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General Science
PROGRAMMED
LEARNING
LABORATORY

Teacher's Guide and Resource Book

BOOK 3

Energy and Work

MATTER IN MOTION

The Macmillan Company
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FROM THE EDUCATION AND PSYCHOLOGY STAFFS OF ACCELERATED INSTRUCTION METHODS CORPORATION

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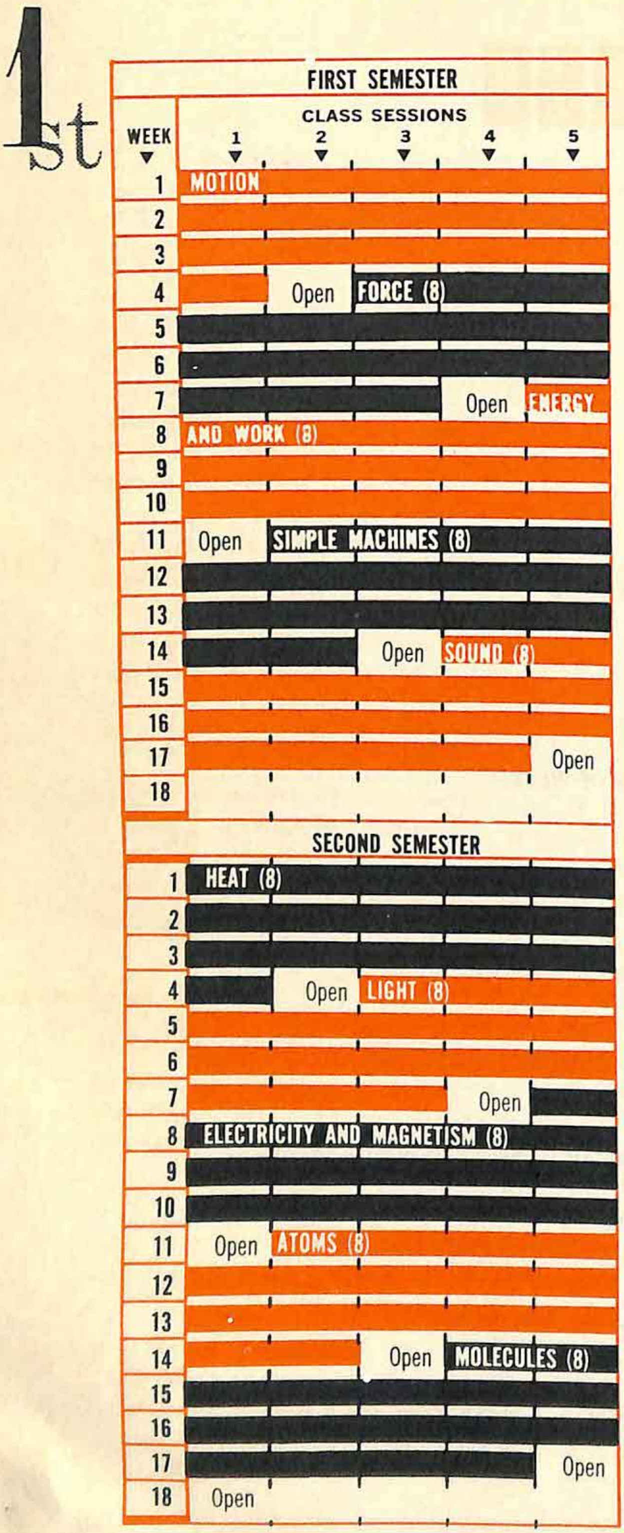
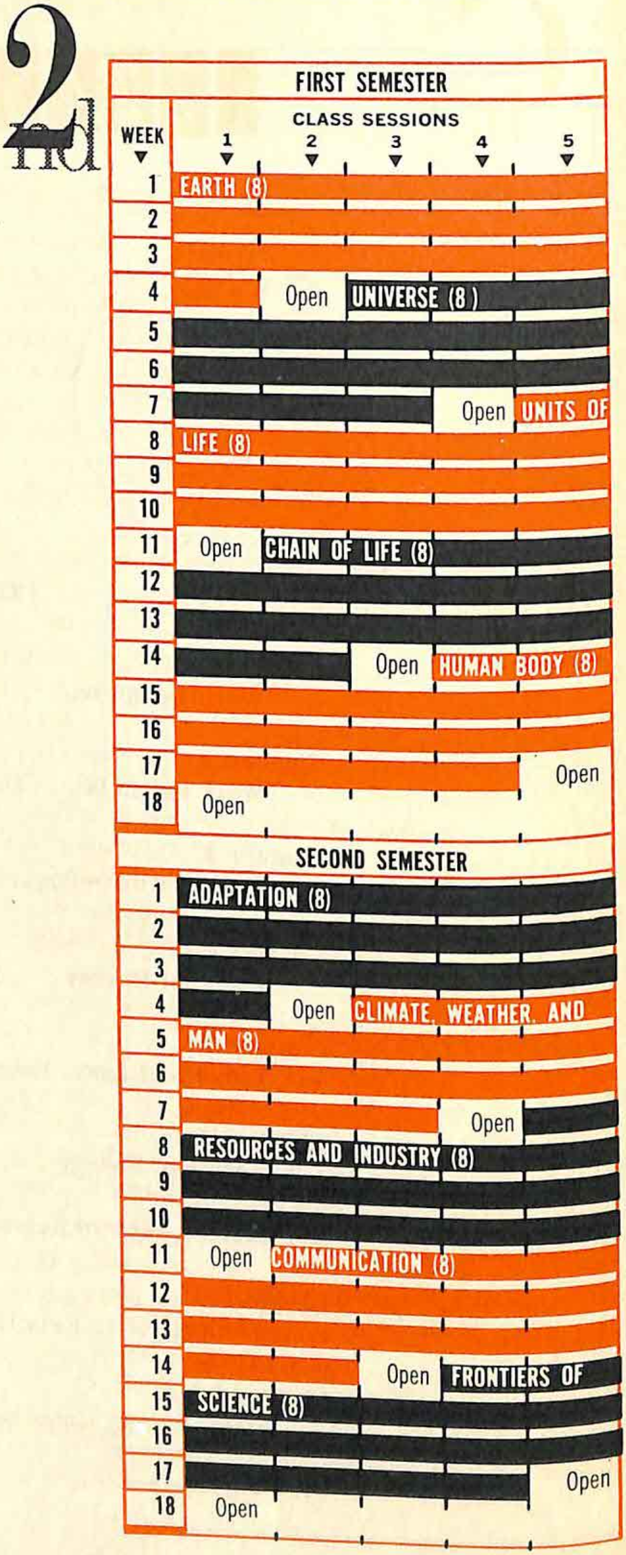
TWO-YEAR GENERAL SCIENCE COURSE





Chapter 1 2 3 4 5 6 7 8

A TEACHER'S VIEW OF ENERGY AND WORK

The myriad movements, sounds, changes of light and shadow, and gradations of heat and cold—all these things that make up our experience of the world around us—require the transfer of energy. The very sensing of change necessitates the doing of work. Thus it is often difficult to fulfill the role of observer, and scientists are continually faced with the need for finding new ways to make the seemingly unobservable more sensible. Once detected, energies are more apt to eventually become measurable, and then describable, by physical laws. These laws are discovered only by investigation of observable, though sometimes apparently almost accidental, changes in the universe. To be of service to man they must be checked and rechecked before becoming useful in the control of the physical environment.

Such was the course of the development of Newtonian and modern physics. Our understanding of the relationships discovered and described within the older framework now is seated comfortably on the foundations of our immediate experience. But this comfortable and sensible seat can no longer be our resting place, for this is a world of change, which does not permit a resting place. The Newtonian conception of the interplay of energy and work that provided a useful pattern for the engineer was a puzzling one for the physicist. A few observations lay outside this pattern and defied adequate description in the vocabulary of the older physics.

These observations suggested the existence of a larger physical framework—one that would require a new vocabulary and the altering of basic assumptions. This was hinted at by Albert Einstein. Relativity was the answer to this need, and today no study of energy and work can be complete without some discussion of the brief, but expressive, formula $E=mc^2$. Other consequences of shifting horizons in science must also be discussed in any study of energy and work.

Book 3 of the AIM General Science Programmed Learning Laboratory develops the concepts of energy and work from the world of Newtonian physics and carries them on into a more modern focus. Of course the relativistic concepts of Einstein can be little more than introduced, but the materials of this course have proved to be readily understandable by students at the junior high school level. The discussion materials of this guide also help to lead the student into better insight and to lay a groundwork for appreciation of discoveries still in store for us.

After your students have completed the programmed lessons in Book 3, ENERGY AND WORK, they will be familiar with these broad concepts:

A scientific definition of work and the fact that work done is proportional to force and distance.

The formula Work = Force × Distance (in the direction of the force)

The concept of the transfer of energy

Power and units of power

The concepts of potential energy and kinetic energy and the relation between them

Various forms of energy

The equivalence of mass and energy

In addition to the discussion materials, there is the Teacher's View of Relativity, which precedes Chapters 7 and 8. It is suggested that this be read enough in advance of the class study of the materials covered to permit you to use the supplementary readings if you so desire. It is also assumed that the teacher has made himself acquainted with the contents of the frames. The concepts of sound, heat, light, electrical, and magnetic energy are treated separately and more fully in Volume 2, THE FLOW OF ENERGY.

STUDY TARGETS Chapter 1 introduces your students to the book and immediately presents the following basic ideas necessary for an understanding of work and energy.

WORK requires the use of ENERGY. This energy is PAID to the objects on which work is done.

FORCE is not itself the expenditure of ENERGY. A force may be exerted for any amount of time without any energy being paid out.

FORCE must move an object through some DISTANCE for WORK to be performed or ENERGY to be used.

The WORK done is PROPORTIONAL to the FORCE and to the DISTANCE through which it moves an object.

1 This sheet of paper has a certain weight.
Because of gravity it presses down on your desk.
Does the paper do any work on the desk? Explain.

ANSWER: No. Nothing is moved through any distance.

REVIEW: Frames 8–11

DISCUSSION STARTER Two men find that their automobiles are out of gas. One pushes against his car until he is too exhausted to push any more, but the car doesn't move. The other man owns a much smaller car and is easily able to push it to the corner gas station without getting tired at all. Does either man do any work on his car?

POINTS: Only the second man does work (on his car). He applies force and moves an object (his car) through a distance (to the corner). The first man applies force, but he does not move the object.

DISCUSSION STARTER

If the first man is exhausted, and the second is hardly tired, how is it that the second man did work and the first did not?

POINTS: Work is not the same as force. The first man may have applied much more force than the second. The application of force may be tiring because work *is* done *within the body*, even if the work doesn't show anywhere else. So the first man is exhausted, but although he applied force and tired himself, he did not succeed in moving the object and so he has done no work *on the object*.

QQ

2 Suppose your watch stops, and even though you wind it, the hands do not move.
Is the force of the wound-up spring doing work?
If the watch begins to run, you know it must use up energy.
Where does this energy come from?

ANSWER: No. This energy was stored in the spring when you did work winding the watch.

REVIEW: Frames 39–45

DISCUSSION STARTER

When a gymnast springs on a trampoline, does he do work? How is energy used? Why can't he go on springing without exerting himself?

POINTS: When he first springs up, the gymnast does work lifting his own body. When he falls, the weight of his body due to gravity plus the force due to his inertia of motion cause force to be applied to the trampoline. Work is done on the material of the trampoline, and it moves down. The energy is passed on to the trampoline, and, in turn, it then has the capacity to do work. It does work on the gymnast's body, pushing him up into the air again. This passing back and forth of energy goes on until there is not enough left to raise the gymnast and not enough for his body to push the trampoline down. The energy is lost through friction, his partial inelasticity when his feet touch the trampoline, and as his body passes through the air. Consequently, the gymnast must continue to supply energy and to expend it by jumping up sufficiently to replace the losses of energy.

3 What two things would you need to know to find how much work you would have to do on a box to lift it to a high shelf?

ANSWER: 1. The weight of the box
2. The height of the shelf

REVIEW: Frames 37–40

DISCUSSION STARTER When a baseball player swings and misses the ball, does he do work? Does he do work when he hits the ball? Discuss a situation in which a batter swings and hits the ball and the ball is caught by a fielder. What possesses energy? Where is work being done? What are the relevant forces and distances?

POINTS: Whenever the batter swings, he does work, whether he hits the ball or not. He does work on the bat by applying force where he grips it and by moving it through a distance as he swings. Thus he expends energy. It is transmitted to the bat, which is then able to do work on the ball. Force is applied to the ball at the place where the bat meets it, and the ball is then moved through a distance until it has a high speed. So work is done on the ball—energy is passed on to the ball. This means that the ball is now able to do work, which it does when it is caught by the fielder. The ball does work on the fielder because force is applied wherever the ball strikes his glove and moves its padding a small distance and pushes on the fielder's hand and arm.

DISCUSSION STARTER If we knew the color, age, and price of an object, what could we say about the force necessary to move it? How much can you say right now about the force required to lift a prune?

POINTS: We could say nothing about the force required to move an object if this were all we knew about it. Neither could we say anything specific about the force required to lift a prune. We have said nothing about the mass of the prune nor about how far it is to be lifted. However, because of our use of formulas, we can say that the force required to move a prune can be discovered in the same way that we can discover the force required to move a mountain. Why do we contrast a mountain and a prune in this discussion?

4 If you know a force is acting on an object, do you also know that work is being done on the object?
Can you always tell that a force is doing work on an object?

ANSWER: No. The force may be moving or heating the object. No, sometimes you cannot tell.

REVIEW: Frames 7-10, 20-22

DISCUSSION STARTER How do we know that work is being done on a bowling ball sitting on the ground in the sun?

POINTS: The bowling ball is being paid heat energy by the sun. We know this because the ball's temperature changes. As heat energy is added to the ball, the kinetic energy of its molecules increases.

DISCUSSION STARTER What types of measurement would indicate the operation of force and the expenditure of energy?

POINTS: Any measurements of change indicate the expenditure of energy and therefore the doing of work. For instance, the measurement of the change of position of an object that has been moved by a force may indicate the distance through which force has operated. The measurement of change in temperature indicates the expenditure of heat energy. The measurement of time makes use of the regular expenditure of energy in the force that runs the measuring device, whether that force is the one found in an Egyptian water clock, in an electric alarm clock, in a wind-up clock, or in a clock that measures time by the nuclear decay of radioactive substances. Other examples may easily be discovered.

Experiments

Experiment 1 is the only demonstration experiment for this chapter. One of the major points to be brought out in this experiment is a problem of measurement, for in many experimental situations the instruments of measurement will themselves interfere with the accuracy of the results. For example, in this experiment the balance must be supported during the pulling of the block or it will add too greatly to the weight of the block and will increase the friction to too great a degree for an accurate measurement to be obtained. This is well worth discussing in connection with the experiment (in Chapter 2) in measuring the work done against friction. Also, the surface on which the experiment is done must be the smoothest obtainable. A possible extension of this demonstration involves the use of a block of dry ice, obtainable from an ice cream manufacturer, as the bearing surface. It must be handled with great care to avoid injury from frostbite.

Key to Conclusions 1. Work is being done in all instances. In the second instance the work is being done on the spring in the balance. The same thing is happening in part (1), but the important part of the work in part (1) is the lifting of the weight. Sliding friction, not the law of inertia of motion, is responsible for the small reading of part (4); overcoming inertia and the static friction between the block and the table causes the greater reading of part (3).

2. This problem offers the students a reminder of Newton's first law of motion. Ideally, if the car were completely free of friction, were traveling on a completely level surface, and had no resistance from the air, the only fuel necessary would be that needed to get the car moving. However, the car does have these other factors to deal with, and fuel is needed to keep it moving.

Student's Supplementary Reading

What is Energy? Posin, Dan Q. Benefic Press, Chicago, Ill., 1.80

Push and Pull; The Study of Energy. Blackwood, Paul. McGraw-Hill Book Co., Inc., New York, N. Y., 3.00

Orbit: A Picture Story of Force and Motion. Ruchlis, Hy. Harper & Brothers, New York, N. Y., 2.75

Wonderful World of Energy. Hogben, Lancelot. Garden City Books, Garden City, N. Y., 2.95

On the Various Forces of Nature. Faraday, Michael. Thomas Y. Crowell Co., New York, N. Y., 2.75

Films

Story of Engines and Energy. 50 frames. Your Lesson Plan. Silent, with captions. Color. Rental: 1.50
Summary: Basic concepts of how engines work. Meaning of force, energy, work, and relationships.

Energy and Work. 16 mm. 12 min. Encyclopaedia Britannica. Sound. Color. Rental: 4.00
Summary: Work means using energy. It takes energy to do work. Energy can be stored; for example, as potential energy (in gasoline and other fuels, in a hanging sandbag, etc.). There is kinetic energy in all moving objects. Energy can be changed from one form to another.

Forces. 16 mm. 15 min. Encyclopaedia Britannica. Sound. Color. Rental: 5.00
Summary: A force is a push or a pull. Pairs of forces change the shape of an object. Machines make it possible to change forces. Three kinds of forces are magnetic, electrical, and gravitational.

Introducing Energy. 52 frames. Your Lesson Plan. Sound (record); captions. Color. Rental: 3.00
Summary: Basic concepts of energy

Energy. 16 mm. 29 min. NET. Sound. B&W. Rental: 4.75
Summary: Why we need energy and where it is obtained. Kinetic and potential energy are explained. Charts and diagrams showing its use and results in work are included.

Teaching Aids

Intelligent Man's Guide to Science. Vol. 1, Physical Sciences. Asimov, Isaac. Basic Books, Inc., New York, N. Y., 7.50

Modern Physics. Dull, Charles E. Holt, Rinehart and Winston, Inc., New York, N. Y., 4.96

Growth of Physical Science. Jeans, Sir James. Fawcett Publications, Inc., New York, N. Y., .50

Your World in Motion; The Story of Energy. Barrow, George. Harcourt, Brace and World, Inc., New York, N. Y., 2.95

Physics for Everybody. Beiser, Germaine. E. P. Dutton & Co., New York, N.Y., 3.50

> Just as no man lives or dies to himself, so no experience lives or dies to itself. Wholly independent of desire or intent, every experience lives on in further experiences. Hence the central problem of an education based upon experience is to select the kind of present experiences that live fruitfully and creatively in subsequent experiences.*
>
> —John Dewey

*Dewey on the subject of experience, from EXPERIENCE AND EDUCATION, The Macmillan Company, 1959, used by permission of Kappa Delta Pi and E. I. F. Williams, Editor.

Chapter 1 **2** 3 4 5 6 7 8

STUDY TARGETS

Chapter 2 introduces work units, reinforces the concepts learned in Chapter 1, and emphasizes that work is directional. The main ideas presented are as follows:

A UNIT OF WORK is a measure of HOW MUCH WORK has been done on an object.

The FOOT-POUND-WEIGHT is the unit of work we will use, and we will shorten it to FOOT-POUND (abbreviation: ft-lb).

When a force moves an object through a distance, the amount of work done on the object is equal to FORCE × DISTANCE. We abbreviate this to W = F × D.

DISTANCE as used in this formula must be only the DISTANCE IN THE DIRECTION OF THE FORCE.

1 Work can be measured in terms of force and distance. What unit of work is used in this chapter? What is the formula we can use to calculate the work done in performing a particular job?

ANSWER: The foot-pound

Work = Force × Distance
(foot-pounds = pounds × feet)

REVIEW: Frames 49, 54–56, 61–65

DISCUSSION STARTER

In Book 2 we learned that force is directly proportional to mass when acceleration is constant. This means that an increase in mass results in a proportionate increase in the force needed to achieve the same acceleration. A decrease in mass produces a proportionate decrease in the force needed. Now consider the formula we have just learned: Work done = force × distance. In this formula what is the relation of work done to force; of work done to distance? Is work done proportional to either force or distance? Is it directly proportional to F or D? Explain the relation between the three quantities without using the words "directly" and "proportional." What do these words mean?

POINTS: In the formula W = F × D, W is directly proportional to both F and D. That W is proportional to F and D means that any change in F or D produces a corresponding change in W. That W is directly proportional to F and D means that any change in F or D produces a corresponding change of the same kind in W. That is, if F or D is increased, W will increase; if F or D is decreased, W will decrease. If we knew only that W is proportional to F, then we would know that any change in F produces a change in W, but it would be possible that W increases when F decreases. To know the relation exactly, we must know that W is not only proportional but directly proportional to F and D.

DISCUSSION STARTER The unit of work we are dealing with is the foot-pound-weight. Someone might suggest that we use a unit in which distance is measured in miles and force in tons-weight; this could be called the mile-ton-weight. Is the foot-pound-weight the only correct unit in which to measure work done? What is the reason for choosing the foot-pound-weight instead of some other unit?

POINTS: No, the foot-pound-weight is not the only correct unit, but neither is it the "wrong" unit. It is simply the unit we have chosen: We could have chosen any other unit that is a product of force and distance. We know that the quantity of work done is determined by two quantities—force and distance. Therefore, our unit of work, which is a measurement of the quantity of work done, will also have to be a combination of a distance quantity and a force quantity. However, we want to choose convenient measures of these quantities. Force can be measured in pounds-weight, ounces-weight, tons-weight, or any other unit of force. Distance can be measured in feet, centimeters, inches, yards, miles, and so forth. We find it convenient to measure force in pounds-weight and distance in feet, so we choose the foot-pound-weight as the unit of work. This does not make it the one correct unit. It is simply a convenient unit to use, since we frequently want to talk about distances that are conveniently measured in feet and forces that are conveniently measured in pounds-weight. For instance, raising a 1-pound-weight book 1 foot off the ground uses a certain amount of energy. If we use the foot-pound-weight, we measure this as 1 foot-pound-weight. If we use the mile-ton-weight, we would have to call this a 1/10,560,000 mile-ton-weight (1/5,280 × 1/2,000), a correct but inconvenient number to use in calculations. Usually the foot-pound-weight is referred to simply as the foot-pound.

DISCUSSION STARTER The units of pounds and feet are not the only ones that can be used to measure work. In the metric system (used by most countries instead of our English system of units, which uses pounds and feet) one of the units of force is the dyne and one of the units of distance is the centimeter (about 2/5 inch). If we were to apply a force of 1,000 dynes to move an object through 10 centimeters in some direction, how much work can we say we have accomplished and in what new unit of work is it expressed?

POINTS: The new unit of work resulting from multiplication of the dyne by the centimeter may be thought of as the dyne-centimeter. However, the metric system has a name for the work done by a force of

1 dyne acting through a distance of 1 centimeter. This name is the erg. Thus, 1 erg equals 1 dyne-centimeter. (An erg is about the energy you would need to blink an eye.) The answer to the problem stated above would be: Work is equal to

1,000 dynes × 10 centimeters = 10,000 dyne-centimeters = 10,000 ergs

Perhaps you would like to think up a new name for the foot-pound.

2

Suppose you had your choice of jobs and wanted to do the least amount of work. Which of these two jobs would you choose? Why?

Job A. Carrying a 3-pound suitcase to a height of 100 feet

Job B. Raising a 130-pound bar bell straight up to a rack 1 foot above the ground

ANSWER: You would choose Job B. Job A requires 300 foot-pounds of work; Job B requires only 130 foot-pounds.

REVIEW: Frames 65–69

3

What is the least force required to lift a 1,000-pound-weight race-horse? Explain your answer.

ANSWER: 1,000 pounds-weight

REVIEW: Frames 66–68

4

Suppose a pillar has supported a half-ton stone block for 1,000 years.

A. Has the pillar exerted a force against the stone block for 1,000 years?

B. Has the pillar been doing work on the block for 1,000 years?

ANSWER: A. Yes. The pillar has exerted an equal and opposite reaction force against the block for 1,000 years.

B. No. To do work on an object, the force exerted must move the object in the direction the force acts.

REVIEW: Frames 80–82

DISCUSSION STARTER So far, we have been considering work as a quantity that is determined by two other quantities: force and the distance moved. We have been saying that once the quantities of force and distance are known, the quantity, or amount, of work done can be computed. And we have represented this relation by a formula: $W = F \times D$. Now that we have the formula we can use it as long as we know any two of the quantities involved; if we know W and D, we can calculate F, or if we know W and F, we can calculate D. And in some cases we might want to know how much energy an object possesses before it has done any work on other objects. We would know beforehand that it possesses a certain number of foot-pounds of energy, and that when this energy is used, it will be possible to get that number of foot-pounds of work done. When we know this—the number of foot-pounds of work an object can do—do we then know exactly how much work (by moving a certain force through a certain distance) the object can do? What else do we need to know? When the amount of work that can be done is known, what can we say about the relation of force to distance?

POINTS: No, we have not described a particular job that can be done when we know the amount of work that can be done; all we know is how much work is involved; we know that innumerable jobs could be done. Suppose, for instance, that when you swing a hammer, the hammer has the energy to do 100 foot-pounds of work. It could, then, move a 1-pound weight 100 feet, or a 2-pound weight 50 feet, or a 100-pound weight 1 foot, and so forth. In order to know exactly what job can be done we must know, in addition to the amount of work that can be done, either the force required or the distance. If we know the force required to move the object, then we can use the work formula to calculate the distance the object will move because of the force. Or, if we know the distance the object will be moved, we can use the formula to calculate the force that must be applied. For the same amount of work, the relation between force and distance is inversely proportional, that is, the greater the force required, the less distance the object can be moved; the less force required, the farther it can be moved. Notice that the formula can be rewritten: $D = W \div F$, when the force required is known; or $F = W \div D$, when the distance to be moved is known. If W remains the same—if we already know how much work can be done—then the greater F becomes the smaller D must be and vice versa. Try substituting numbers for the letters in these two new variations of the work formula.

DISCUSSION STARTER Suppose a ball is thrown to you. Whoever throws the ball pays it a certain amount of energy, and now the ball has energy and in stopping is able to do some work. To catch the ball you will have to let it spend its energy by doing work on you. If the ball is thrown hard, and if you don't want to hurt your hand, should you hold your arm stiff and not allow your hand to move, or should you allow the ball to push your hand back as you catch the ball? Explain this situation in terms of the relationship between force and distance.

POINTS: You should allow your hand to be pushed back. The number of foot-pounds of work done on your hand will be the same, no matter how you catch the ball, because once it is in motion the ball has a fixed amount of kinetic energy. But although you can't alter the foot-pound-weight total, you can affect the number of feet (distance) and the number of pounds-weight (force). The object the ball does work on in stopping is your hand. This is the object it moves through a distance. The greater the distance the less the force—since force and distance are inversely related. So let your hand be moved. If, for instance, the ball can do 200 foot-pounds of work, there will be 200 pounds-weight of work done if your hand is moved 2 feet. You will be unable to prevent your hand being moved some distance; the skin, muscles, and bones will all be "squeezed" at least a small amount. The less you let your hand be moved the greater will be the force against it and the harder the ball will hit your hand. This is the same rule that applies when boxers "roll with the punch." By letting his shoulder be pushed back a bit when it is struck, a boxer lessens the force of the blow's impact. When the work done remains the same, the greater the distance the less the force.

Experiments

In part B of Experiment 1 be sure to emphasize the fact that only the vertical distance is relevant to the calculations. In Experiment 2 the same problem of measurement arises that was discussed in Experiment 1. Be sure that the weight of the scale is accounted for before calculating the amount of work done against friction. The demonstration using dry ice as a bearing surface, described for Experiment 1, might also be useful here.

Key to Conclusions 1A. The amount of work done in lifting the book will vary with the weight of the book and the height of the desk, but every student would do the same amount of work in lifting the same book to the same desk. The double-weight book lifted one-third the distance would require only two-thirds the amount of work. 1B. If the lightest student in the class computes the amount of work needed to lift him to the fifth step, simple calculations will tell how far the heaviest student in the class is lifted when the same amount of work is done. Answers will vary, of course.

2. Answers will vary.
3. Answers will vary.

Student's Supplementary Reading

World of Measurement. Johnson, Donovan A. Webster Publishing Co., St. Louis, Mo., .85

Doing Work. Blough, Glenn O. Row, Peterson and Co., Evanston, Ill., .49

Friction All Around. Pine, Tillie S. McGraw-Hill Book Co., Inc., New York, 2.50

Realm of Measure. Asimov, Isaac. Houghton Mifflin Co., Boston, 2.75

Films

Friction—How It Helps and Hinders. 16 mm. 14 min. University of Illinois. Sound. Color. Rental: 4.70
Summary: Discusses problems relating to the effects of friction and how it modifies many of our activities and devices.

Man Measures the Universe. 46 frames. UNESCO. Silent. B&W. Rental: 1.00
Summary: Methods of measuring lengths, from the infinitely small to the infinitely large. Based on the traveling science exhibit organized by UNESCO.

Story of Machines. 29 frames. Curriculum Materials Corp. Silent. Color. Rental: 1.00
Summary: Basic inventions and adaptations of machines and their modifications for use today.

Machines Conquer Gravity and Friction. 48 frames. Your Lesson Plan. Sound (record) with captions. Color. Rental: 3.00
Summary: Basic machines and how they work.

Understanding the Physical World Through Measurement. 16 mm. 13 min. National Bureau of Standards. Sound. Color. Free.
Summary: Man's struggle to harness energy. Demonstrations illustrating transfer between potential and kinetic energy and between mechanical, chemical, heat, and other forms of energy.

Teaching Aids

Your World of Science. Booklet. Porter Chemical Company, Hagerstown, Md. Free. Describes the atom. Discusses measurement: metric system and metric units. Simple experiments and rules for the small laboratory.

History of Measurement (posters). Ford Motor Company, The American Road, Dearborn, Mich. Free. 17×22. One set of 8 posters per teacher. Color. Original and present applications of basic measuring units.

Dimensions, Units, and Numbers in the Teaching of Physical Sciences. R. G. Ford. Teachers College, Columbia University, 525 W. 120th St., New York.

Amazing Story of Measurement. Lufkin Rule Co., Saginaw, Mich. Free in reasonable quantities. From hand measurement to the scientific measuring instruments of today.

Chapter 1 2 **3** 4 5 6 7 8

STUDY TARGETS

Chapter 3 develops the concept of power as the rate of doing work and introduces the unit called the horsepower. The following are the additional points.

To know a RATE we must know the TIME INTERVAL during which something takes place.

POWER is the RATE OF DOING WORK.

Power can be measured in FOOT-POUNDS/SECOND.

The HORSEPOWER is equal to 550 FT-LBS/SEC.

Q 1

How much work must an escalator do in lifting a 100-pound man from the basement to the first floor, a distance of 15 feet?

ANSWER: 1,500 foot-pounds of work

REVIEW: Frames 110–112

DISCUSSION STARTER

From our study of power and work thus far, can you think of any physical reasons why jockeys are always small, light men? Can you guess why doctors advise people not to put on a lot of extra weight?

POINTS: First, there must be no confusion when we consider work done inside the body and work done outside the body on an object to which force is applied. Everyone knows that a man must move much more slowly and that he tires much faster if he is carrying a heavy load rather than a light one. This is because much of his energy goes into the task of counteracting the force of gravity by holding the load up. As we have learned, by merely holding a package up, you expend your body's energy without performing any work outside your body. Similarly, if a horse carries a heavy man, it must expend more of its body energy in merely keeping the man off the ground, which means that it will have less available energy for its running muscles. Thus the horse carrying the heavy man cannot run as fast, and it cannot keep up its speed for as long a time as can a horse carrying a light man. Doctors advise people not to put on too much weight because by doing so they increase the amount of energy they must use up merely to keep themselves in an upright position. Then, whenever they have to do something, their extra weight makes it necessary to use up still more energy, which puts additional strain on the body. In later life this may be a serious factor in heart ailments.

DISCUSSION STARTER If you knew that a machine could throw a number of red objects 20 feet up and a number of blue objects 40 feet up, what could you say about the machine? About the objects?

POINTS: The distance through which the objects are moved by the force of the machine is twice as much in one case as it is in the other case. There are several possibilities in this problem. First, if we assume that the machine exerts an equal amount of force on each object, then we must also assume that the red objects weigh twice as much as the blue ones and so would be moved one-half the distance up. Second, we might assume that the machine was a sorter, and that the two sets of objects had equal weight. In this case the machine would have to "see" the colors of the objects and exert twice as much force on the blue objects as on the red ones. Third, we might assume that the machine "sees" the colors of the objects but that the weights of the objects differed at random rather than according to their color. In this case the machine would have to weigh the objects and calculate how much force was required to throw each object the necessary distance. Only experimentation could tell us which of these possibilities is the true one.

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DISCUSSION STARTER Probably you could, with little difficulty, lift a 5-pound-weight block to a height of 5 feet, drop it, and repeat this action 40 times. Even if you are not very strong, you could lift it once an hour, ten hours a day, for four days. What is the total amount of work in foot-pounds-weight that you would have done on the block? But could you, by yourself, lift a 1,000-pound-weight beam 1 foot off the ground, even if you had years to try? How much work must be done? Discuss the difference between the two jobs.

POINTS: The total work done on the block would be 1,000 foot-pounds, which is exactly the work done in lifting the 1,000-pound weight 1 foot. The impossibility of your doing the second job is due to the fact that a 1,000-pound-weight force is needed just to raise the beam, and this force must be applied all at once in order to overcome the downward pull of gravity on the beam. A machine at least powerful enough to exert a 1,000-pound-weight force all at once would be needed to raise the beam off the ground. However, only a 25-pound-weight force would be needed to do the work each time the block was raised. Your body would easily be capable of exerting a 25-pound-weight force.

Q 2 What do we mean by "power"?

ANSWER: Rate of doing work

REVIEW: Frames 122-127

DISCUSSION STARTER The amount of work done is determined by force and distance. Power is determined by work and time. Write the formula from which we can calculate power. Now write the formula without using work. What is the relation between power and time? Between P and W? Between P and F and D? Are they related? How? Name some other quantities that have this relation to time.

POINTS: $$\text{Average Power} = \frac{\text{Work}}{\text{Time}} \qquad \text{Power} = \frac{\text{Force} \times \text{Distance}}{\text{Time}}$$

Power is directly proportional to force and distance. The greater the F or D the greater the P Notice that power is directly proportional to work, and work is directly proportional to force and distance. If work is done at a uniform rate, power is inversely proportional to time: The more power, the less time it takes to do a job. The more time it takes to do a certain amount of work, the less power is involved. Both speed and velocity have this inverse relation to time.

DISCUSSION STARTER What is the difference between work and power? Discuss what it means when we say that one machine does more work than another instead of saying that one machine has a higher power rating than another.

POINTS: Work requires the expenditure of energy. Work is done when a force moves an object through a distance in the direction of the force. Therefore, the amount of work done must be in terms of a distance quantity and a force quantity. We are using feet and pounds-weight. Power, on the other hand, is a measure of the rate at which work is done. So we must also consider a time quantity. If we use seconds as our interval of time, then power is a measure of work done (force × distance) in a time interval of one second. If one machine can do more work than another, then:

a. it can move the same number of pounds-weight through a greater number of feet than the other machine can, or

b. it can move a greater number of pounds-weight through the same distance that the other machine can, or

c. it can move a greater number of pounds-weight through a greater distance than the other machine can, that is, it can do more foot-pounds of work.

But to say that one machine has a higher power rating than another is to say that it can do the same amount of work in a shorter time.

3 If a motor does 1,000 foot-pounds of work in 1 hour, what is the power of the motor?

ANSWER: 1,000 foot-pounds per hour

or

$$\frac{1}{550} \times \frac{1}{3.6}\ \text{hp} = \frac{1}{1,980}\ \text{hp}$$

REVIEW: Frames 125–127, 133

DISCUSSION STARTER Scientifically, the idea of power is very useful. If we did not use it and simply confined ourselves to the idea of work, what kinds of difficulties might we encounter? What sorts of problems would we be unable to deal with satisfactorily?

POINTS: The idea of work does not take account of time. This is why we need to combine work and time to get an average rate of doing work. Unless we consider time, it is almost impossible to give a sensible evaluation of how much work a man or a machine can do. For instance, it may take a considerable amount of energy against friction to move 1,000 pounds-weight from Chicago to Boston. But a man might do this job, without any help from machines if he were given unlimited time. Or an elevator might lift 3,000 pounds-weight to the top of a building in one minute, while a newer elevator might lift the same load to the same height in 30 seconds. Clearly, the second elevator can do something the first cannot, but we have no way of scientifically formulating this until we consider time along with force and distance. Then we are able to show that the second elevator has the higher power rate.

4 To figure the power of a motor we need to know three things: Two of them are: (1) the force the motor exerts to move something (2) a certain distance.

What is the third thing we must know?

ANSWER: The time the force takes to move something through a distance

REVIEW: Frames 122–133

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Experiments

In Experiment 1 only the horizontal component of the force is relevant, and in Experiment 2 only the vertical component is used. Experiments 1 and 2 may be done simultaneously by two teams.

Key to Conclusions 1. Answers will vary. The vertical component of the force does work against gravity. Most important, this vertical component decreases the amount of friction as the block tends to be accelerated by the force of gravity. To show this, compare the results of this experiment with those of Experiment 2, Chapter 2.

2. Answers will vary from student to student, depending on individual weight and the time it takes to climb the stairs. If five people were pulling a weight, the individual components of horsepower would be immaterial. The only information necessary to compute their horsepower would be the weight of the object they were moving, the distance through which they move it, and the time required.

3. Answers will vary. 1 horsepower = 746 watts

Student's Supplementary Reading

What Is Gravity? King, F. M. Benefic Press, Chicago, 1.80

Scientists Behind the Inventors, "James Watt." Burlingame, Roger. Harcourt, Brace and World, Inc., New York, 3.25

Energy and Power. Irving, Robert. Alfred A. Knopf, Inc., New York, 2.75

More Power to You; A Short History of Power from the Windmill to the Atom. Schneider, Herman. William R. Scott, Inc., New York, 2.75

Films

To Enrich Mankind. 16 mm. 23 min. Jam Handy Organization. Sound. Color. Rental: 3.00
Summary: Story of mechanical energy in the development of the United States. The six basic machines and their modern applications.

Work, Time and Power. 16 mm. 14 min. University of Illinois. Sound. Color. Rental: 4.70
Summary: Demonstrates meaning of power as the rate of doing work. Foot-pound and horsepower are clearly illustrated.

Gravity: How It Affects Us. 16 mm. 14 min. Encyclopaedia Britannica. Sound. Color. Rental: 3.00
Summary: Illustrates importance of gravity by showing some of the things it does. Demonstrates gravity studies of Galileo and Newton.

More Power for You. 16 mm. 19 min. General Motors Corp. Sound. Color. Free.
Summary: Story of power at work in America.

Evolution of Power. 16 mm. 11 min. AV-ED Films. Sound. Color. Rental: 6.00
Summary: Progress from muscle power to atomic power and the ways in which the various methods work.

Teaching Aids

Ghost Town that Came to Life. Booklet. 16 pp. Allis-Chalmers Manufacturing Company, Industries Group, Advertising Department, Milwaukee 1, Wis. Free. How a utility converts coal into electricity; a trip to a powerplant. Explains volts, DC, AC, ampere, and watt.

Blown Out Fuses. Booklet. 7 pp. Allis-Chalmers Manufacturing Company. Free. Classroom quantities. Explains cause of blown fuses as low horsepower and tells what can be done about it.

Gravity. Gamow, George. Doubleday & Co., Inc., New York

Anchor paperback, .95

A Power Primer. Booklet. 101 pp. The Story of Power. Booklet. 51 pp. Free. General Motors Corporation, Educational Relations Section, Public Relations Staff, General Motors Technical Center, Warren, Mich. Write on school stationery. Introduction to the internal combustion engine; covers muscle, wind, water, atomic, and sun power.

James Watt. Taylor, B. St Martin's Press, Inc., New York, .50

Electrical Measurements. Smith, Alva W. J. W. Edwards Publishing Co., Ann Arbor, Mich., 1.50

Chapter 1 2 3 **4** 5 6 7 8

STUDY TARGETS In this chapter the two forms of energy called potential energy and kinetic energy are distinguished, and their relationship is described. The following points are emphasized.

Stored energy, such as that in a suspended weight, is called POTENTIAL ENERGY.

A raised weight is said to have potential energy of position. The amount of potential energy in a raised weight is determined by the amount of energy "paid" to it in lifting it from the ground.

The energy possessed by a body in motion is called KINETIC ENERGY.

As an object falls toward the earth, its potential energy of position becomes less at each instant as it changes to kinetic energy of motion, which becomes greater at each instant.

Q 1 To lift any object to a height above the ground takes energy. If you place a book on a shelf 3 feet above the ground, does the book have more energy than it did when it was on the ground? Explain.

ANSWER: Yes. It has the energy that was paid to it in lifting it to the shelf: potential energy of position (PE).

REVIEW: Frames 147, 149-152, 154, 155

DISCUSSION STARTER Does potential energy do work? How must we describe the use of energy when an object with potential energy does work? What nonscientific meanings of the word "potential" do you know of that are like its meaning in the term "potential energy"?

POINTS: So long as energy is potential in form, it does not do work. Kinetic energy does do work, and potential energy can be converted to kinetic energy. We are using the word "potential" in a nonscientific way when we say that someone is a potential violinist. But when he is finally able to play the violin, he is no longer a potential violinist—he is a violinist.

DISCUSSION STARTER Can an object be paid potential energy only by lifting it above the ground? If not, can you think of something that might have potential energy even while it was lying on or near the ground?

POINTS: No. There are other ways for an object to acquire potential energy. Remember the explanation of potential energy in the previous discussion. If we think about potential energy in this way, many things have potential energy. For instance, the spring in a jack-in-a-box has the potential energy to spring the jack into the air when the box is opened. Consider the energy stored in a rocket that attains escape velocity and then "falls" up from the earth. We might even say that this rocket has potential energy of position with respect to the point it will reach when it has expended the chemical energy stored in its fuel. A boy standing at homeplate has potential energy that will be released when he hits the ball.

DISCUSSION STARTER We say a 10-pound block of lead has no energy when it is resting on the ground. But if we lift it to a tabletop 4 feet off the ground, what happens? Does it have energy now? How much? How is the block of lead different now? Would we find anything different if we cut it open? Has its appearance changed? What is the difference? Explain exactly what PE of position is.

POINTS: The only thing different about the block of lead is its position relative to the earth. This is why we call this form of energy PE of position, position that permits the force of gravity to act on the object and move it. When objects have PE of position, they themselves do not change form, as, for example, chemicals change form when there is a change from chemical energy to heat energy. Potential-energy difference involves only a change in the position of objects.

DISCUSSION STARTER As you probably know, the astronauts who have orbited the earth in space vehicles have experienced extended periods of weightlessness. During such a period objects normally held down by the force of gravity are freely falling, as is the cabin containing them, so they go floating around the cabin if given a little nudge. Would you say that these objects that are floating about in the space vehicle have potential energy of position with respect to the floor of the cabin? Would you say that they have PE of position with respect to the surface of the earth?

POINTS: Because there is no force pulling any of these objects toward the floor of the cabin, they have no potential energy with respect to that floor, regardless of how far off it the objects may rise. There cannot be potential energy due to the position of an object with respect to a specific surface unless there is a force attracting the object to that surface.

By the same reasoning, all the objects in the cabin of a space vehicle still have a very large potential energy of position with respect to the surface of the earth. This is because the whole orbiting spaceship is still under the influence of the gravitational pull of the earth, and if the spaceship merely slowed down, its inertia of motion would be lessened and it would be pulled down toward the earth. Thus both the spaceship itself and every individual object within it have a large PE of position with respect to the earth.

DISCUSSION STARTER Suppose you throw a ball as high as you can, straight up. At what point is its PE of position greatest? Describe the energy transformations as the ball goes up and then falls back to the ground.

POINTS: Just before the ball is thrown up from the surface of the earth, it will have no PE of position or KE of motion. When you throw the ball, you give it KE of motion by doing work on it. As the ball travels higher, this KE becomes less and less, and the ball slows down until it stops rising altogether. At this momentary point of rest all the energy you gave the ball (except that which was spent against air resistance) is stored as the ball's PE of position. Its PE of position is the greatest at this highest point. As the ball begins to fall, more and more PE is changed to KE as the ball's motion increases. When the ball finally strikes the ground, its PE of position is zero, and its KE of motion is greatest.

Q 2 If we consider that a 10-pound weight has a PE of 0 while resting on the ground, what would its PE be at a height of 100 feet?

ANSWER: 1,000 foot-pounds

REVIEW: Frames 156, 166–170

DISCUSSION STARTER On what does an object's PE of position depend? What does this have to do with the force of gravity?

POINTS: An object's PE of position depends upon force and distance (height). The force required to give PE of position depends upon the gravity force that must be overcome in raising the object. In a weightless condition there would be no such thing as PE of position because no work would have to be done to raise objects.

DISCUSSION STARTER Jones is standing on the street, and right next to him rests his big suitcase. As soon as he sees his friend down the street, Jones shouts to him, "My suitcase has no potential energy of position because it is lying on the ground."

But just then Jones hears a voice and looks down a manhole, in which he sees a workman digging in the sand 10 feet below street level. The workman yells to Jones that his suitcase must have some potential energy of position because if Jones put the suitcase over the hole and let go of it, it would drop down and might pay some unwelcome energy to the workman below. If you were there, whom would you agree with? Does the suitcase have potential energy of position?

POINTS: In a sense, both Jones and the workman are correct. When we talk about potential energy of position, we are talking in RELATIVE terms. For example, imagine a mining shaft 1,000 feet below the earth's surface. If we take the bottom level of this shaft as our reference level, only objects at the bottom of the shaft would have no potential energy of position. In that case, every object on the earth's surface would have a potential energy of position (in foot-pounds-weight) of 1,000 times the object's weight. Thus, if you weigh 100 pounds-weight and you have a desk that weighs 40 pounds-weight, you have a potential energy of position WITH RESPECT TO THE BOTTOM OF THE MINING SHAFT of 1,000 × 100 or 100,000 foot-pounds-weight, and your desk would have a PE of position with respect to the bottom of the shaft of 40 × 100 or 40,000 foot-pounds-weight. But if we take a shaft 2,000 feet deep as our point of reference, you will have twice the PE of position (200,000 foot-pounds-weight) that you had at 1,000 feet, and so will your desk (80,000 foot-pounds-weight). There is no definite, unchanging PE of position for any object on the earth. Whenever we talk of PE of position, we always choose a reference level and call this the point of 0 (zero) PE of position. Usually this reference level is ground level, our commonest place of activity. When Jones says his suitcase has zero potential energy, he is using ground level as his reference level. The man in the hole is 10 feet below the ground, and he is taking the bottom of the hole in which he is standing as his reference level. So both Jones and the workman are right: At ground level the suitcase has zero PE of position; but with the bottom of the hole 10 feet below ground level as a reference, the suitcase has a PE of position that equals 10 times the weight of the suitcase.

QQ

3 Is the PE of a stone falling to the ground increasing or decreasing? What change is there in the stone's kinetic energy as it falls closer and closer to the earth?

ANSWER: Its PE is decreasing as its height above the earth is decreasing. Its KE becomes greater and greater, until wind resistance will let it move no faster or until it strikes the ground.

REVIEW: Frames 185–192

DISCUSSION STARTER At a pool table one player shoots, hitting the white (cue) ball with his cue. This ball then rolls a distance and strikes another ball. The cue ball then rolls on a few more inches and stops. The second ball rolls until it falls into a pocket. Describe what happens in terms of energy and work. What forms of energy are present? What energy transformations occur?

POINTS: Shooting the cue ball gives it KE of motion. When this ball hits another, some of its energy of motion is given to the second ball, though not all of it, because the cue ball continues to move for several inches. The cue ball spends the rest of its KE of motion against the force of friction between itself and the table and soon stops. Meanwhile, the second ball rolls to the pocket, where its PE of position in relation to the ground is converted into KE while it falls downward into the pocket and does work on the material of the pocket. Notice that all the balls on the table and in the pockets have PE of position, for they are above the ground. The second ball spends only part of its PE of position because it does not fall all the way to the ground.

DISCUSSION STARTER Imagine a metal ball attached to a long string that is hanging motionless from the ceiling. This is a pendulum in its rest position. If someone said that a swinging pendulum is a device for converting potential energy into kinetic energy and kinetic energy into potential energy, would you know how to explain what he meant?

POINTS: When you deflect the pendulum in order to start it swinging, you are paying the pendulum an amount of potential energy equal to the product of the height to which you raise it and the weight of the ball (the force exerted on the ball by gravity). Just before you let it go, the pendulum has potential energy of position but no kinetic energy. When you let the pendulum go, it swings in a downward arc. As it does so, the potential energy is converted into kinetic energy. At the moment the ball passes through its rest position, all the potential energy that you originally stored in it by deflecting it has been converted to kinetic energy, and since there is no force to stop it, it uses this energy to continue its motion. After passing through its rest position, which is the lowest point in its path, the pendulum continues on in an upward swing. As it does this, energy begins to be translated back into potential energy of position. At a certain height at the other end of its path—about as high as you lifted it originally—all the kinetic energy has been converted back to potential energy, so the pendulum stops momentarily. But it immediately begins moving downward again, turning the potential energy of position back into kinetic energy and then to potential energy once again. If it were not for friction and air resistance and the spinning of the earth, such a pendulum would go on swinging forever, retracing its path exactly on each swing.

DISCUSSION STARTER Imagine a block of metal at rest on a sidewalk. You pick up a heavy hammer and pound on the block about five times. If you then touch the block you can probably feel that it is quite warm. Give a description of what happens in terms of energy from the time you decide to lift the hammer.

POINTS: When you lift the hammer, you endow it with a certain amount of potential energy. As you bring the hammer down, all the potential energy goes into the production of kinetic energy. This, plus the energy you pay it as you swing it down forcefully instead of merely dropping it, gives a larger total kinetic energy to the hammer. When it hits the block of metal on the sidewalk, the hammer must stop, since there is nowhere it can go. The kinetic energy of the hammer must be transformed into other forms of energy. The sound of the hammer striking the block indicates the transformation of kinetic energy to sound energy, but most of the kinetic energy is transformed into heat energy, and as a result the block becomes quite warm. Thus we see that some of the energy has been transformed several times.

Experiments

In Experiment 1 of this unit it should be pointed out that the point of zero gravitational potential energy is arbitrary. The students on any floor of the building are considering the floor of their own classroom to be the point of zero PE. It should be stressed that the amount of gravitational potential energy is dependent only on the distance through which the book would fall to reach the point at which it would be stopped. A ladder may be substituted for the flight of stairs. Experiment 4 causes a small explosion.

Key to Conclusions 1. The PE of the book on the floor is zero. The path taken and the speed with which the path is covered are immaterial in calculating the potential energy of the book at the top of the stairs. Changing the distance the book has to fall or the weight of the book are the ways of changing the PE of the book at the top of the stairs. Different amounts of work are done on the ping-pong ball in each situation.

2. Answers will vary. One of the major ways in which this principle is used in daily life is in the operation of spring scales. Other instances are readily imaginable.

3. If we were to trace the energy changes in this experiment, we would start with solar energy, which is responsible for the plant growth that eventually became gas, a fossil fuel. The chemical energy of the burning gas was then transformed into the heat energy of the boiling water. Finally, the moving steam from the boiling water acted as mechanical energy by pushing on the vaned wheel.

4. The small explosion of this experiment releases energy in the form of noise, light, and heat. It is possible to demonstrate some release of mechanical energy during this experiment by standing a small wall of folded paper close to the point of explosion.

Student's Supplementary Reading

Experiments in the Principles of Space Travel. Wong, Jeanyee. Thomas Y. Crowell Co., New York, 2.75

Heat. Herbert, Don. Doubleday & Co., Inc., New York, 1.25

What Is Heat? Munch, T. W. Benefic Press, Chicago, 1.80

Wonder of Heat Energy. Ruchlis, Hy. Harper & Brothers, New York, 3.79

What Makes the Wheels Go Round: A First-Time Physics. Huey, Edward G. Harcourt, Brace and World, Inc., New York, 3.00

Films

Energy from Gasoline Engines. 50 frames. Your Lesson Plan. Silent, with captions. Color. Rental: 1.50
Summary: Rapid combustion and cycle of the gasoline engine. Explains parts and types of engines.

Introduction to Heat. 52 frames. Your Lesson Plan. Sound (record) and captions. 30 min. Color. Rental: 3.00
Summary: Basic principles.

Story of Heat. 16 mm. 14 min. University of Illinois. Sound. Color. Rental: 4.70
Summary: Introduction to basic sources and properties of heat. Shows how friction produces heat. How man has learned to harness heat to supply energy. Basic scientific principles of nuclear submarines and application of atomic power.

Heat. 50 frames. Science Slides Co. Sound (record) with text. B&W. Rental: 3.50
Summary: Transfer, conduction, convection, and radiation and their application in engines and other devices.

The Steam Engine: How It Works. 16 mm. 11 min. Encyclopaedia Britannica. Sound. B&W. Rental: 3.00
Summary: Appraisal of the work of Watt. Shows how steam is used to produce motion.

Wind and Water Energy. 49 frames. Your Lesson Plan. Sound (record) and captions. Color. Rental: 3.00
Summary: Basic principles.

Teaching Aids

Experiments with Gas. 35 pp. Available free in most areas from local gas companies. If not, write to American Gas Association, 420 Lexington Avenue, New York 17. Designed for junior high students.

Heat—Science and Economics of Its Control. Free. Johns-Manville Sales Corp., Mr. W. A. Ransom, Manager of Motion Pictures, 22 E. 40th St., New York 16. 16 mm., sound, color. 26 min. Problems of heat transfer and how one company solves them.

Introduction to the Heat Engine. Free. Shell Oil Co., Film Library, 624 S. Michigan, Chicago 5, Ill. 16 mm., sound, color. 22 min. Development of the engine from Greece to the present. Thermal efficiencies of various heat engines and efforts to increase them.

Science Principles and Your Automatic Gas Range (ED-8)
Science Principles and Your Automatic Refrigerator (ED-12) Teaching kits. Free, write on school stationery. American Gas Association, Educational Service Bureau, 420 Lexington Avenue, New York 17. Experiments, teachers guides, wall charts. Others available.

Combustion. Film. Classroom Film Distributors, Inc., 201 N. Occidental Boulevard, Los Angeles 26, Calif. 15 min. Sound. Color. Rental: 10.00. Factors necessary for combustion; its results and industrial uses. High school level.

Chapter 1 2 3 4 **5** 6 7 8

STUDY TARGETS This chapter continues the discussion of kinetic energy and introduces the method of calculating the amount of kinetic energy possessed by a moving object. The following main ideas are stressed.

The amount of work a moving object can do is equal to the amount of kinetic energy it has.

The amount of kinetic energy a moving object has depends upon its SPEED and its MASS.

The kinetic energy of a moving object can be calculated by using the formula

$$\text{KINETIC ENERGY} = \frac{\text{MASS} \times \text{SPEED SQUARED}}{2}$$

$$KE = \frac{m \times v^2}{2}$$

NOTE: Since we do not have to take direction into consideration, the v in $\text{KE} = \frac{mv^2}{2}$ refers not to velocity but to speed (the speed of the object at some given instant).

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1 What change is there in the amount of energy in an object when we do work on it? To do any work we must have energy. How would you define energy in terms of work?

ANSWER: The energy increases. To do work on an object, energy must be paid to it.

REVIEW: Frames 147-150, 152, 153, 188

DISCUSSION STARTER What is the relationship between KE and m and KE and v expressed in the kinetic energy formula $\text{KE} = \frac{mv^2}{2}$? Which will increase the kinetic energy more—doubling the mass or doubling the speed?

POINTS: Kinetic energy is directly proportional to m. Therefore, if the mass, m, is doubled, the KE is also doubled. But the relationship of KE and v is different. KE is directly proportional to the square of v. So, if the speed, v, is doubled (multiplied by 2) the KE is multiplied by 2 squared, or 4.

DISCUSSION STARTER If we already know the relation between energy and work, what kinds of observations might lead us to consider the idea that moving bodies have energy because of their motion?

POINTS: We would notice that many bodies do no work when at rest, but that they can do work when they move. If they can do work, they must have energy. But since they can do this work only when they are moving, it must be energy of motion. If a bowling ball is placed next to a pin, it does no work on the pin, even if it touches it. But if the ball contacts and moves the pin because of its own motion, it obviously does work on the pin. This energy available to do work on the pin must be due to the ball's motion, for nothing else has changed.

DISCUSSION STARTER When an object is actually in motion, it is often very difficult to measure its mass and velocity. If we didn't know the mass and velocity of a moving object, how else might we determine its KE of motion?

POINTS: We could either measure the amount of energy paid to the object, as when we know the PE of position and are then able to find the KE of motion it accumulates while it falls all the way to the earth, or we could measure the amount of work the object does because of its KE of motion. For instance, we could calculate the KE of a flying arrow by seeing how far it penetrated into a bale of hay.

Q 2

Which of these situations best illustrates kinetic energy?

A. The stored energy of a ball 100 feet above the ground
B. The energy of a bullet speeding toward its target

ANSWER: The energy of a bullet speeding toward its target

REVIEW: Frames 152, 153, 177–179, 188

DISCUSSION STARTER In Chapter 5 we saw that in some cases there are two ways to calculate an object's KE of motion. What kinds of situations are these, and what are the two ways of making the calculation? One way involves mass and speed; the other involves force and distance. Are these two formulas entirely unrelated? Can you see a way in which the mass and speed from one formula ($KE = \frac{mv^2}{2}$) are related to force and distance in the other formula (PE of position $= F \times D$)?

POINTS: We can calculate KE when we know the object's mass and speed, or when we know how much energy was paid it. The formulas are closely related. The force required to lift the object is related to its mass, while the distance it falls and its initial downward velocity determine the speed with which it will be moving when it strikes the earth. There is a third way to calculate KE of motion—once the object has stopped moving. Compute the amount of work, due to its motion, it did in stopping, that is, how much KE of motion it expended.

3 On what two things does the kinetic energy of a moving object depend?

ANSWER: Mass and speed

REVIEW: Frames 220–222

4 On what two things does an object's potential energy of position depend?

ANSWER:
1. The distance through which the object can fall
2. The mass of the object

REVIEW: Frames 171–173

DISCUSSION STARTER What must have happened when an object that is not in motion acquires kinetic energy of motion? For an object to acquire kinetic energy of motion must it first have potential energy of position? Is it possible for an object to have PE of position and then acquire KE of motion without losing any of its PE of position? Give an example.

POINTS: Work must be done on an object to give it KE of motion. It does not have to have PE of position. For instance a football lying on the ground has no PE of position with respect to the ground, and it is given KE of motion when it is kicked. A pool ball resting on a table does have PE of position. If you push it across the table, you give it KE of motion, but as long as it does not move closer to the ground, its PE of position does not decrease.

5 Which object would have the greater kinetic energy?

A. A 10-pound rock traveling at 30 miles per hour
B. A 10-pound rock traveling at 87 miles per hour

ANSWER: A 10-pound rock traveling at 87 miles per hour

REVIEW: Frames 220-222

DISCUSSION STARTER Everyone knows the story of how the boy David killed the giant Goliath by the clever use of his sling. The stone that struck Goliath must have possessed tremendous kinetic energy. Do you think this energy of motion resulted more from the mass of the stone or more from its speed?

POINTS: Since it probably was a small stone, most of its kinetic energy must have come from the speed with which the stone hit Goliath. We can see from our formula that the kinetic energy of motion is PROPORTIONAL TO THE SQUARE of the speed of the object. If David, in his excitement, had hurled the stone at a speed only two times faster than he had ever hurled it before, the stone's kinetic energy of motion would have been four times greater!

DISCUSSION STARTER If you were using a stone to drive a stake straight down into the ground, could you drive it deeper by dropping the stone on it or by throwing the stone down at it? Explain your answer in terms of KE of motion and explain where the KE comes from.

POINTS: If you hit the stake squarely, throwing the stone would result in more work done. More KE of motion would be possessed by the stone. Gravity does work on the falling stone because of the change in the stone's PE of position, which gives it added KE of motion. But the stone can also receive additional KE if you exert your own force on it. KE of motion can come from any source that possesses energy and is able to do work.

DISCUSSION STARTER When a body with KE of motion does work, it does not have to use all its energy of motion. Give examples—cases in which an object with energy of motion does work but still retains some energy of motion. Can you see a way of relating these three things: KE before doing work, KE after doing work, and work done?

POINTS: When the brakes of a car are applied, some of the car's KE of motion is made to do work against the friction between the wheels and the brakedrums, but the car does not have to stop. Another example is that of a shot in shuffleboard, in which both pucks move after the collision. The KE before doing work minus the KE still possessed after doing work equals the amount of energy given up when work was done. That is, the change in KE is equal to the work done. Notice that this is true for the object on which work is done as well as for the object that does the work.

Q 6

Would the kinetic energy of a 100-pound rock traveling at 50 miles per hour be greater or smaller than that of a 10-pound rock traveling at the same speed? Why?

ANSWER: The 100-pound rock has 10 times the mass of the 10-pound rock and would therefore have 10 times the KE.

REVIEW: Frames 223-227

DISCUSSION STARTER Large semitrailers are trucks that travel for long distances over large highways. Many of these trucks move as fast as automobiles—between 60 and 70 miles per hour. Do you know why the airbrakes used on these trucks are so much larger and more powerful than those used on automobiles that go just as fast and often faster?

POINTS: Since a brake is used to slow down a moving vehicle, it must somehow convert the vehicle's kinetic energy of motion to other forms of energy as fast and as safely as possible. The brake does this by applying a rubbing surface to the moving axle and thus dissipates the kinetic energy of motion into heat through the resulting friction. Since a truck going at a certain speed has a much greater mass than a car going at the same speed, the resulting kinetic energy of motion is much greater. Therefore, an automobile brake would be far too small to turn all the kinetic energy of motion of the truck into heat. After braking once or twice, the whole surface of the brake would probably be rubbed away by the truck's axle. A truck usually has a much larger rubbing surface so that more of its kinetic energy of motion can be turned into heat as rapidly as possible.

DISCUSSION STARTER Kinetic energy of motion depends upon two quantities: mass and speed. What kinds of observations might suggest to a scientist the relationship between these quantities? How could he check this relationship and formulate it more precisely?

POINTS: Kinetic energy of motion depends upon m and v. If two objects with different masses travel with the same speed, one can do more work in stopping than the other can. For instance, how many bowling pins can you knock down with a marble rolling just as fast as a bowling ball? However, a bowling ball that rolls slowly toward the pins will do less work than one that travels faster. Once m and v are known to be the determining quantities, the formula can be worked by varying the size of m and v in several experiments. For example, calculate the work that can be done by a 16-pound bowling ball traveling at a given speed; then move the ball at twice the original speed and check the increase in work done.

Experiments

The experiments of this unit are more properly described as problems. The computations required by these problems are designed to give the student a closer understanding of the principles discussed in the chapter and practice in the manipulation of the formulas involved. Limitations of space preclude a complete description of the derivation of these formulas, but it may be found in any good sourcebook. A few notes of clarification are necessary here.

The KE calculation used in Experiment 1 is designed to give an answer in gravitational units, that is, in foot-pounds. By using just F, m, and a to work through the formula the student can get a full understanding of the substitution of $\frac{F}{a}$ for m (mass) in the KE formula.

If a 1-pound mass is given an acceleration of 1 ft/sec/sec, the force acting on the mass is 1 poundal. The poundal is defined as the unit force that will give an acceleration of 1 ft/sec/sec to a 1-pound mass.

Therefore: if $m = 1$ lb and $a = 1$ ft/sec/sec

$$F = 1\ \underline{\text{lb} \times 1\ \text{ft/sec/sec}} = 1\ \underline{\text{lb} \times \text{ft/sec/sec}} = 1\ \text{poundal}$$

Whenever you see the expression "lb × ft/sec/sec" in a formula, you can substitute the word "poundal."

$$F = 10\ \text{lbs} \times 80\ \text{ft/sec/sec}$$

$$\text{or } F = 800\ \underline{\text{lbs} \times \text{ft/sec/sec}} = 800\ \text{poundals}$$

A 1-pound mass falling near the surface of the earth is acted on by a gravity force of:

$$F = m \times a$$

$$F = 1\ \text{lb} \times 32\ \text{ft/sec/sec (acceleration due to gravity)}$$

$$F = 32\ \underline{\text{lb} \times \text{ft/sec/sec}} = 32\ \text{poundals}$$

If the 1-pound mass is weighed on a standard scale at Greenwich, England, its weight will be exactly 1 "pound." More correctly, the scale should read 1 pound-weight. Anywhere on the surface of the earth, an object with a mass of 1 pound is acted on by gravity with a force of very close to 1 pound-weight. We have seen that the force of gravity acting on a 1-pound mass is 32 poundals. In other words, 1 pound-weight equals 32 poundals. If the mass of an object is given in lbs and the speed in ft/sec, the KE is given in foot-poundals.

$$\text{KE} = \frac{mv^2}{2} = \frac{\text{lb} \times (\text{ft/sec})^2}{2}$$

$$\text{KE} = \frac{\text{lb} \times \text{ft}^2/\text{sec}^2}{2} = \text{ft} \times \frac{\text{lb} \times \text{ft/sec}^2}{2}$$

$$= \frac{\text{ft} \times \text{poundal}}{2} = \frac{\text{ft-poundal}}{2}$$

When we substitute the mass calculated from the force formula, that is, when we substitute $m = \frac{F}{a}$ we get our answer in foot-pounds.

$$m = \frac{\text{lb-wt}}{\text{ft/sec/sec}}$$

$$\text{KE} = mv^2 \times \frac{1}{2}$$

$$\text{KE} = \frac{\text{lb-wt}}{\text{ft/sec/sec}} \times (\text{ft/sec})^2 \times \frac{1}{2}$$

$$\text{KE} = \frac{\text{lb-wt} \times \cancel{\text{sec}^2}}{\cancel{\text{ft}}} \times \frac{\text{ft}^{\cancel{2}}}{\cancel{\text{sec}^2}} \times \frac{1}{2}$$

$$\text{KE} = \underline{\text{ft} \times \text{lb-wt}}\ (\text{foot-pound}) \times \frac{1}{2}$$

When a student calculates the kinetic energy of a moving object, he may reason out his answer in this way:

> If an object weighs 10 pounds-weight, its mass must be 10 pounds because on the surface of the earth a 10-pound mass is attracted to the earth by a gravity force of 10 pounds-weight.
>
> If the mass figure used in the calculation is in pounds and the speed is in feet per second, the kinetic energy will be given in foot-poundals.
>
> Since 1 foot-pound is equal to 32 foot-poundals, the answer in foot-poundals must be divided by 32 to get it in foot-pounds.

FORCE	MASS	ACCELERATION	ENERGY
1 poundal	1 lb	1 ft/sec/sec	foot-poundal
1 lb-wt	1 lb	32 ft/sec/sec	foot-pound

1 foot-pound = 32 foot-poundals

The kinetic energy of the bicycle in Experiment 1A is calculated as follows: Using the formula provided for finding the mass of the bicycle, $m = \frac{F}{a}$, the bicycle's mass equals $\frac{35 \text{ lbs}}{32 \text{ ft/sec/sec}}$ or 1.09 lbs-mass, as we have seen. The speed of the bicycle, 15 miles per hour, is 22 feet per second.
Using the formula $\text{KE} = \frac{mv^2}{2}$ we find that the $\text{KE} = \frac{1.09 \times (22)^2}{2} = 263.73$ ft-lbs. The total formula, involving all of the units, is

$$\text{KE} = \frac{35 \times \left(\frac{15 \times 5280}{3600}\right)^2}{32 \times 2}$$

To find the answer in poundals multiply this answer by 32. For these experiments it is

suggested that each student work out at least one complete set of the calculations and that the work be apportioned in such a way that all of the calculations are finally made.
Key to Conclusions 1. The translation of kinetic energy to potential energy would require that the foot-pounds of energy of each of the moving bodies be used to lift those bodies into the air. The amount of potential energy of the bodies, once this has been done, will equal the amount of kinetic energy that has been used to raise them.
2. To give the sled a velocity of 20 miles per hour when it already had a velocity of 10 miles per hour would require half as much work (if friction is ignored).
3. If you double the velocity of the car, the KE will be four times as great.

Student's Supplementary Reading

Light. Herbert, Don. Doubleday & Co., Inc., New York, 1.25

Your World in Motion. Barrow, George. Harcourt Brace and World, Inc., New York, 2.95

Fun With Science. Freeman, Mae. Random House, Inc., New York, 1.50

Isaac Newton. Sootin, Harry. Julian Messner, Inc., New York, 2.95

Engines, Atoms and Power. Williams-Ellis, Amabel. G. P. Putnam's Sons, New York, 2.00

Films

Demonstrations With Light. 16 mm. 12 min. University of Illinois. Sound. Color. Rental: 3.20
Summary: Illustrations of various theories of light, its nature, speed, and means of propagation. Especially effective in motivating student interest in the physical sciences.

Kinetic Energy. 16 mm. 15 min. NET. Sound. B&W. Rental: 3.00
Summary: Explores principles of kinetic energy. How springs have stored energy that does work for us, etc.

Inertia of Motion. 16 mm. 10 min. University of Illinois. Sound. B&W. Rental: 2.15
Summary: Proves that the amount of inertia an object has depends on its weight.

Light and Heat. 29 frames. Prentice. Silent. Color. Rental: 4.00
Summary: Visible light as a form of radiant energy. Stresses man's use of heat.

Science of Light. 16 mm. 11 min. Churchill. Sound. Color. Rental: 4.00
Summary: Experiments, difficult to do in the classroom, on refraction, speed of light, where light goes, how light is absorbed and changed to heat, etc.

Producing and Using Light. 52 frames. Your Lesson Plan. Sound (record) and captions. Color. Rental: 3.00
Summary: States basic principles.

Teaching Aids

Straight-Line Kinematics. Film. 34 min. 16 mm. A-V Center, Division of University Extension, Indiana University, Bloomington, Ind. Sound. B&W. Rental: 5.75. Summary: Shows inter-relationship between speed, distance, and acceleration.

How To Make a Demonstration Fuel Cell. Booklet. 8 pp. Free. Esso Research and Engineering Co., Public Relations Division, P. O. Box 45, Linden, N. J. Summary: Operating principles; directions for building a fuel cell and for assembling a fuel-cell-powered transistor radio.

Breakthroughs in Science. Asimov, Isaac. Houghton Mifflin Co., Boston, 4.00

Energy. Lodge, Oliver. John F. Rider Publisher, Inc., New York, 1.25

Light. Efron, Alexander A. John F. Rider Publisher, Inc., New York, 2.25

S.C.E.R.T., West Bengal
Library
Calcutta
25/3, B. C. Road

Chapter 1 2 3 4 5 6 7 8

STUDY TARGETS

This chapter introduces the idea of the interconvertibility of different forms of energy and presents the law of conservation of energy, which states that energy cannot be created or destroyed. These concepts are presented:

CHEMICAL ENERGY is a potential form of energy that is released as light, heat, and sound energy by chemical reaction.

Sound, electrical, heat, light, and nuclear energy are all forms of energy that are capable of performing work.

ENERGY NEVER DISAPPEARS: It merely CHANGES INTO DIFFERENT FORMS.

The LAW OF CONSERVATION OF ENERGY states that the total amount of energy in the universe ALWAYS REMAINS THE SAME.

1 $W = F \times D$ (in the direction of the force) What does this formula mean?

ANSWER: Work done equals force applied times the distance moved by the object to which the force is applied.

REVIEW: Frames 66-69, 78-80

2 Why, in this program, do we call energy and work the scientific twins? What do we mean when we say "ENERGY IS CONSERVED"?

ANSWER: Energy and work always occur together. Energy cannot be destroyed; it can only be converted from one form to another.

REVIEW: Frames 257, 283-285

DISCUSSION STARTER

The total amount of energy in the universe remains the same. What about the energy of the earth and its atmosphere? Is earth's amount of energy always the same? If it is changing, give examples of changes in the total amount of energy.

POINTS: The earth's total amount of energy is fluctuating. For example, the earth constantly receives energy from the sun in the form of heat, light, and other radiation. Meteors that enter the earth's atmosphere have KE of motion, which they pay to whatever part of the earth they strike. As they burn up in the earth's atmosphere, they pay energy in the form of heat (and sometimes light) to the surrounding air. The earth also loses energy when, for example, gases escape from the earth's atmosphere. When a rocket is sent out into space, it possesses KE of motion. If the rocket leaves the earth's atmosphere permanently, it pays its energy of motion somewhere else, and the earth has lost it.

DISCUSSION STARTER In many situations we have discussed, we have disregarded air resistance. Actually, from the standpoint of the law of conservation of energy, air resistance and all frictional forces are very important. Why?

POINTS: It takes energy to overcome these forces. The energy spent in doing almost any job will be used, in part, against them. If we don't consider them, we will be unable to account for some of the energy that went into the job. Scientists have done much careful experimental work to determine exactly how much work must be done against friction in various situations.

DISCUSSION STARTER Jobs use KE of motion to do work and require energy to overcome friction. Give examples of such jobs and indicate what happens to the energy paid to overcome friction.

POINTS: Some examples are those of a person dragging a crate across the floor, a motor moving a car, and a ship sailing through water. When a driver applies the brakes hard, he creates much frictional pressure, sounds are heard, and enough heat may be generated to burn the rubber tires. When a train stops suddenly, light energy, and sometimes electrical energy, are given off.

3 Does a light bulb destroy the electrical energy it uses? Explain.

ANSWER: No. Part is radiated as heat; part is radiated as light.

REVIEW: Frames 284-287

DISCUSSION STARTER Why do we call chemical energy potential energy? How does this kind of PE differ from PE of position?

POINTS: Chemical energy is energy possessed by a material so constituted that work can be done if and when a chemical reaction occurs that involves the material. Hence, like PE of position, chemical energy does not do work unless it has the right conditions and is transformed. Unlike PE of position, chemical energy is not able to do work because of a position relative to the earth; it can do work because of its chemical structure, which has nothing to do with an object's PE of position.

DISCUSSION STARTER

What kinds of energy changes are involved when two people converse over the telephone?

POINTS: When a person speaks into a telephone, sound energy does work on the telephone transmitter. This energy is converted into electrical energy that can be used to do work miles away. There, it is converted into sound energy again, and it can be heard by the listener. Energy in the form of sound could not travel so quickly nor so far.

4

As a rock falls to the earth does its potential energy increase or decrease? Think of what might happen as a rock hits the ground. You know it does work on the ground as it strikes it, and the rock must have energy to do this work. Explain. Where does this energy come from? Where does it go?

ANSWER: It decreases. As the rock falls, its PE of position is changed to KE of motion. When it strikes the ground, its KE of motion is changed to other forms of energy (such as heat, light, and sound) as it does work.

REVIEW: Frames 184-186, 189, 190

DISCUSSION STARTER

Even though it is impossible to destroy energy, can energy be wasted? For example, most automobiles do not manage to convert even half of the chemical energy of gasoline into the automobile's KE of motion. What happens? How is energy wasted?

POINTS: Wasted energy is not destroyed energy. Wasted energy escapes in unusable forms or is incompletely used. In many jobs kinetic energy is lost as heat paid against friction. Frequently, the best way to improve the efficiency of a machine is not to apply more energy but to cut down the waste, as is done in streamlining a plane to eliminate some air resistance or in muffling an auto's exhaust to cut down the sound energy it produces.

5 When you burn a candle, it gives off heat energy and light energy. When gasoline is "burned" in the engine of a car, it gives the car energy of motion. What do we call the form of energy stored in a candle and in such fuels as gasoline before it is released?

ANSWER: Chemical potential energy

REVIEW: Frames 264–266

DISCUSSION STARTER Music involves sound energy. What kinds of energy can be used to make music?

POINTS: Chiefly kinetic energy, such as that produced by drawing a violin bow, by blowing air into a wind instrument, and by depressing piano keys, which causes mallets to strike strings. An electric organ changes electrical energy to sound; so does a phonograph or a radio.

DISCUSSION STARTER You are able to do work. Therefore, you must have energy. What form is it in? Where does it come from?

POINTS: Most of the body's energy is stored as chemical energy. This comes from the food we eat, which itself has chemical energy. Within the body it goes through chemical reactions and is changed into compounds, such as glucose (a type of sugar), which can be stored. When energy is needed, these compounds go through chemical reactions that produce the kinetic energy that enables the muscles to move and do work.

DISCUSSION STARTER Suppose you wanted to know how much chemical energy is contained in a gallon of gasoline. Could you find out by measuring the amount of kinetic energy that results when the gasoline is used in an automobile engine to move the car?

POINTS: No. Not all of the PE will be converted into the motion of the car. As the gasoline burns in the engine, there will be heat and light energy and energy of motion in the vapor that escapes through the exhaust. And there will be sound energy. All of these result from the chemical energy of the gasoline, but they will not be measured if you measure only the motion of the car.

Experiments

The experiments in this unit deal with changes in the form of energy. Although the experiments are set up to demonstrate some particular process of change (chemical to electrical, mechanical to electrical, and so forth), forms of energy other than these essential ones enter into the experiments. These "secondary" forms of energy should be discussed in each case, but the students should be encouraged to find them themselves. The first two experiments require the use of a current meter, the construction of which is described in the experiment. This instrument increases its efficiency with the increase in the number of coils of wire around the compass. For the second experiment a demonstration of the problems of measurement introduced in Experiment 2 of Chapter 1 might well be made. Use the current meter as it is described in Experiment 1 of this unit and then increase the sensitivity of the instrument by adding 30 coils of wire to the existing 20 coils.

Key to Conclusions 1. In this experiment the essential energy change is from chemical energy to electrical energy. A secondary change in the form of energy is the shift from electrical energy to mechanical energy in the movement of the needle in the current meter. This is accomplished by a shift in the magnetic field controlling the direction of the needle in the compass. A change from chemical energy to electrical energy also takes place in the batteries.

2. The answers will be demonstrated. The secondary energy changes that take place involve the change of chemical energy in the muscles of the person moving the magnet to mechanical energy and the change of electrical energy to mechanical energy in the movement of the needle in the measuring instrument. The initial form of energy in the hydroelectric systems is the potential energy of the water that flows down long tubes and spins the magnets or coils in the generators.

3. In this experiment the initial energy transformation is the same as that in Experiment 2. There is an intermediate energy transformation of mechanical energy into electrical energy that causes the glow in the fluorescent tube.

Student's Supplementary Reading

Adventures in Electrochemistry. Morgan, Alfred. Charles Scribner's Sons, New York, 3.50

Experiments with Atomics. Beeler, Nelson F. Thomas Y. Crowell Co., New York, 2.75

Superpower: The Story of Atomic Energy. Ross, Frank, Jr. Lothrop, Lee & Shepard Co., Inc., New York, 3.00

A Boy and A Motor. Yates, Raymond F. Harper & Brothers, New York, 2.50

Films

Exploring Electromagnetic Energy. 16 mm. 15 min. Film Association. Sound. Color. Rental: 6.25
Summary: Introduction to electromagnetic energy and to some of the ways we use it every day.

Electricity From Chemicals. 16 mm. 30 min. NET. Sound. B & W. Rental: 4.75
Summary: How chemicals liberate energy in the form of electricity. Demonstrates zinc-lead reaction.

Mechanical Energy and Electricity. 33 frames. Filmstrip House. Silent, with captions. Color. Rental: 5.00

Summary: Electrical theory and magnetism in relation to generators and motors. How to make a motor. Practical uses of generators and motors.

How to Produce Electric Current with Magnets. 16 mm. 12 min. Encyclopaedia Britannica. Sound. Color. Rental: 4.00
Summary: How to make an electromagnet. Magnets can be made to produce electric currents. When permanent magnets are moved in relation to a coil of wire, electric current flows in the wire. Machines that use this principle are called generators.

Atomic Energy—Inside the Atom. 16 mm. 15 min. Encyclopaedia Britannica. Sound. Color. Rental: 5.00
Summary: Shows evidence of atoms breaking up, as seen in a cloud chamber. The unbalanced nucleus of a radioactive atom loses particles. Radiation can do work because it carries energy.

Teaching Aids

Accelerators: The Machines of Nuclear Physics. Wilson, R. Robert. Doubleday & Co., Inc., New York, .65

The Atom Comes to Town. Film. United States Atomic Energy Commission, Office of Public Information, P. O. Box 59, Lemont, Ill. Free. Color, 16 mm. Sound. 29 min. Shows how heat from nuclear fission is used to make electricity and what nuclear power will mean. Discusses types of powerplants, kilowatt capacity, and principles.

Parts and Assembly of a Lead Type Storage Battery. Form 3970. Chart. Electric Storage Battery Company, Public Relations Department, P. O. Box 8109, Philadelphia 1, Pa. Free. Request on school stationery. Chart shows parts and assemblies and explains how electrical energy is stored as chemical energy and is then delivered as electrical energy.

Atomic Energy: The Story of Nuclear Science. Jaworski, Irene D. Harcourt, Brace and World, Inc., New York, 4.95. Includes many home experiments.

Electrical Experiments You Can Do from the Notebooks of Michael Faraday. Edison Foundation, Inc., Suite 806, 8 W. 40th, New York 18. 32 pp. Free. Experiments to encourage creative work. Materials required are inexpensive.

Between Chapter 6 and Chapter 7 is an overview of relativity, for the teacher. It is to be read before the students begin Chapter 7.

A TEACHER'S VIEW OF RELATIVITY

To explain the theory of relativity is difficult at best, and a complete understanding of it is almost unavailable to the nonmathematician. Within this course it has had to be discussed in terms of its implications, using descriptive analogies. Some discussion of these things is appropriate before the students work through these chapters in their program books. This presentation is intended to supply materials for this introductory discussion.

The relativity of time is probably the easiest to understand of any of the associated concepts. Time is experienced only as a "now" of existent conditions. The past or the future are not experiential within the observer; they exist only as memory or as foresight within the matrix of the observer's "now." However, if the observer watches a man cutting wood a quarter of a mile away, the sound of the chops will reach him after the sight—in other words, at a later point in time. The observer's "now" is not the same as the "now" of the man chopping wood as far as sound is concerned. Another example of this phenomenon occurs in a fireworks demonstration, when the sight of a skyrocket exploding reaches the viewers several seconds before the sound when actually sound and sight are simultaneous in the explosion. This analogy is quite similar to one that is important to astronomers. When they look at Sirius, one of the nearest stars, the light they see has been on its way to earth for 8.6 years. In other words, the events we see taking place on Sirius actually occurred 8.6 years ago, and events occurring there now won't be part of our "now" until 8.6 years have passed.

Remember (from the study of motion) that speeds can be added, that is, the speed of a thrown ball is the speed with which it is thrown added to the speed of the object from which it is thrown. Also, when an object is moving at 20 miles per hour, it takes no more energy than it did to achieve the original speed to add another 20 miles per hour and make the object travel at a speed of 40 miles per hour. This principle holds true within the system of measurement we ordinarily use, just as "now" for the woodchopper is the "now" for us when we are watching him but are not listening to him. However, as we reach higher speeds, our system of measurement no longer works. There is a limit to the speed at which matter can move, regardless of how much more energy is added to it. That upper limit is the speed of light. The closer we come to the speed of light, the greater the amounts of energy we must add to attain a given increment of speed.

It has been demonstrated that energy and mass are interchangeable forms, different only in state. There is a certain proportional relation between these two forms, but this coefficient of proportion is very small. As an example, if we were to attempt to increase the mass of an object by 1 gram, we would have to pay it 25,000,000 kilowatt hours of energy—67,500 000,000,000 foot-pounds. As this shows, the increase in an object's mass (due to the addition of energy) is normally insignificant. At speeds well below the speed of light there is only a minute increase in an object's mass as its kinetic energy increases. But when speeds close to the speed of light are attained, the increase in mass (due to the energy paid to the moving object) begins to reach really significant proportions.

A useful analogy to help explain the concept of increase of mass with increase of speed is that of the increase in the size of a ship's wake that accompanies increase in the speed of the ship. The wake actually travels with the ship, so we can think of it as part of the ship and as contributing to the ship's mass. An increase in the size of the wake would therefore be analogous to an increase in the ship's mass as the vessel speeded up.

The relation between energy and mass is more aptly described in terms of a vortex—the form assumed by matter in circular motion.

> A vortex is neither a body nor a force; it is both. A force cannot make itself felt unless there is matter to act upon. A vortex needs air in which to appear as a hurricane, or water in which to form a whirlpool. Matter and energy are inseparably connected in a vortex. The greater the energy of a whirling vortex, the more it assumes the qualities of a body. The faster a fan revolves, the more the air vortex around it solidifies. A rubber ball flung at the fan will rebound from the air vortex as if it had been thrown against a wall. If the rate of the fan's revolutions were increased a hundredfold, even a stone could not pierce the vortex.
>
> Modern physicists speak of matter as a special state of energy. Nobody knows what energy is, and the physicist who is in search of the laws of the universe does not ask for the why but only for the what. When energy travels with the speed of light, it is called radiation. When it concentrates at specific points, let us say, as a vortex, it assumes the properties of "mass"; it becomes impenetrable, disputes its place with other vortices, and repels them. Mass is concentrated energy; energy is deconcentrated mass. Einstein created the term "mass-energy" to embody this interchangeability. Mass and energy are not strictly identical but equivalent; mass can be changed into energy, and energy into mass. The process which turns mass into energy is radiation. All radiations travel with the speed of light. Since the speed of light is always the same, it is called a universal constant and is used as the measuring rod of cosmic distances. The light-times—light-seconds, light-hours, light-years—mean the distance in space over which light travels in a given period of time. The distance to the moon is 1.2 light-seconds, the distance to the nearest star outside the solar system is 4.4 light-years.
>
> Einstein has succeeded in expressing the relationship between energy and mass in this formula: $E=m\times c^2$. "E" stands for energy expressed in ergs; one erg is approximately the energy required for a blink of the eye; "m" stands for mass in grams, and "c" (the Latin *celeritas*, speed) represents the speed of light in centimeters per second, amounting to 30,000,000,000, or 3×10^{10}. The square of c, c^2, is $9 \times 10^{20} = 900{,}000{,}000{,}000{,}000{,}000{,}000$. Mass is convertible to 900,000,000,000 times 1,000,000,000 times as much energy as its own weight, the weight expressed in grams and the energy in ergs.
>
> The amount of energy concentrated in mass is, according to this formula, tremendous. Out of one single shotgun pellet we could extract as much energy as all the power stations of the world could produce during twenty-four hours, or, conversely, if all the power stations of the world were to convert their

energy production into mass, we would see after a day no more than a shotgun pellet.

No wonder that, when Einstein published his formula for mass-energy, the physicists shook their heads. This new concept of matter and energy seemed fantastic. But when, on July 16, 1945, the atom bomb exploded, Einstein was at last proved right.*

*From DESIGN OF THE UNIVERSE by Fritz Kahn. Copyright, 1954, by Fritz Kahn. Reprinted by permission of Crown Publishers, Inc.

The following suggested readings provide a more complete discussion of the theory of relativity and its derivation from previous theories.

What Is Relativity? L. D. Landau and G. B. Rumer. 1960, Basic Books, Inc., New York

Relativity for the Layman. James A. Coleman. 1958, Signet paperback

The ABC of Relativity. Bertrand Russell. 1958, Mentor paperback

The Universe and Dr. Einstein. Lincoln Barnett. 1961 (revised), Mentor paperback

Relativity: The Special and General Theory. Albert Einstein. 1961, Crown paperback

Readable Relativity. Clement Durell. 1960, Torch paperback

Chapter 1 2 3 4 5 6 **7** 8

STUDY TARGETS

This chapter reviews prior material and introduces, as simply as possible, the basic idea of the convertibility of mass and energy. The following are the major points made.

Einstein showed that laws of conservation of ENERGY and MASS were related more closely than anyone ever imagined.

The SPEED OF LIGHT OR ENERGY IN A VACUUM is an absolute limit, and nothing in the universe can travel any faster.

Energy paid to an object traveling near the speed of light increases the object's mass. Thus, ENERGY ITSELF MUST HAVE MASS.

Q 1

For billions of years the sun has been radiating heat energy and light energy, some of which is absorbed by the earth and can be recovered for use by man. List some of the ways this energy is used in everyday life. Why can we call coal and gasoline fossil fuels?

ANSWER: This energy is stored as potential energy in the earth's crust in the form of oil and coal. When these fuels are burned, they release heat energy and light energy for home and industrial use.

REVIEW: Frames 303-307

DISCUSSION STARTER

In Chapter 7 you learned that energy has mass. Every day, you can see and feel that the earth must receive a great deal of energy from the sun. Do you think that the earth increases its mass a great deal every day? What do you think happens to this energy?

POINTS: The earth's mass remains fairly constant, although there is probably some slight fluctuation due to the absorption of the sun's energy and the meteorites falling upon it. Part of the energy that reaches the earth from the sun arrives as heat and light. Plants use light as a source of energy during respiration processes. Much of the sun's light energy is reflected back into space. Although heat energy can be absorbed much more readily than can light energy, it too is later radiated back into space. Each time you observe that the air close to a sidewalk is warm for a time after the sun stops shining but soon cools off, you have observed this process in operation. Most of the heat that the sun has paid to the sidewalk is being radiated back into the air and will eventually be radiated back into space.

DISCUSSION STARTER If energy is released when coal is burned, where has that energy come from? Where has it been? What does this illustrate about the earth's relation to the sun? How do you think energy from the sun (and the mass of this energy) is added to the earth?

POINTS: The energy that is released when coal is burned has come from the sun and has been stored underground in the coal (as potential chemical energy). This illustrates the fact that the earth's mass is increased by the storage of energy that comes from the sun. It is in the growth of plants that part of this energy from the sun is stored, but even here the energy is not tied up for long in most cases. The energy that animals use comes from the food they eat, and this energy has come from the sun.

2 In your own words, what do the law of conservation of energy and the law of conservation of mass say?

ANSWER: No energy is ever lost or destroyed in the universe. Because energy has mass, no mass is lost or gained through change of state. Total mass-energy in the universe is constant.

REVIEW: Frames 283-285, 312-315, 364, 365

DISCUSSION STARTER Imagine a wintertime camper. He starts his fire in the morning and burns 10 pounds of wood as he cooks his breakfast and cleans up the campsite. After he leaves the campsite, having first checked to see that his fire has burned out, there remains only a circle of ashes. Soon these ashes are cold, and the melted snow that had been around the edges of the fire stops steaming in the cold and finally freezes. A small snowfall covers the place where the fire had been, and nothing remains of the campsite. Where there had been 10 pounds of wood and then quite a bit of heat and light, there is nothing but snow and perhaps a pound or so of cold ashes. What has happened to the mass of the wood and to the energy of the fire?

POINTS: The discussion should produce its own answers.

DISCUSSION STARTER How do we describe the different forms of energy and differentiate between them?

POINTS: We describe them by stating their effect on matter. We differentiate between them by studying these effects and noting differences and similarities; then we divide the effects into categories. Here are eight commonly accepted forms of energy:

1. Sound
2. Muscular
3. Mechanical
4. Chemical
5. Electrical
6. Heat
7. Light
8. Atomic (nuclear)

DISCUSSION STARTER Sometimes muscular energy is not put into a category by itself. Can you tell why?

POINTS: Muscular energy has three aspects that can be thought of in terms of other categories, that is, chemical, electrical, and mechanical. These three forms, because of the way they are combined in muscular energy, are sometimes thought of as a single category.

DISCUSSION STARTER Why haven't kinetic energy and potential energy been included in the above list?

POINTS: Because all of the above forms of energy can be found in either of these states of energy.

3 In this chapter you learned that Albert Einstein showed that mass and energy are related in a very special way.

A. What do we mean by the term "inertia"? What change is there in an object's inertia if the object's mass increases?
B. Does a loaded truck require more energy to accelerate it than does an empty truck?
C. Does an object's energy increase as it speeds up? What is this energy of motion called?

ANSWER:
A. It increases.
B. The loaded truck requires more force to accelerate it.
C. Yes. It is called kinetic energy.

REVIEW: Frames 327-329, 340, 341

DISCUSSION STARTER Do you think we could use heat energy to add 1 gram of mass to the bowling ball we talked about earlier?

POINTS: No. It would require so much heat energy to raise the mass by 1 gram that the bowling ball would have completely burned away long before that much energy could be added.

4 What is the limit to the speed at which an object can travel? Is there any change in an object's mass as the object is accelerated to near the speed of light? How does this show that energy has mass?

ANSWER: The speed of light: 186,283 miles per second. Yes—the mass becomes greater the closer the object comes to the speed of light. The mass becomes greater in proportion to the energy paid the object.

REVIEW: Frames 344, 345, 350–355

5 Why can we say, as we usually do, that we do not consider that the mass of objects in this part of the universe changes? Under what circumstance does a change in the mass of an object (such as an atomic particle) become great enough to measure?

ANSWER: Their velocities are too low for such change to become noticeable. The change in the mass of an object becomes great enough to measure as the object's velocity approaches the velocity of light.

REVIEW: Frames 357–359

DISCUSSION STARTER A man's fastest running speed is about 20 miles per hour. Why haven't doctors considered what happens to a man's feet when he runs 50 miles per hour? What is the relation between this question and the last quiz question? Can you think of any more instances where the same principle applies?

POINTS: It is undoubtedly true that the effects of running 50 miles per hour would be severer than those of running 20 miles per hour, but, since no man is capable of running at that speed, the occasion for considering it has never arisen. The point is, that for the sake of practicality and on the basis of common experience, we need only consider those things with which we have to deal in doing certain jobs. As we expand our experiences by building machines that make possible actions that have not been possible before, then it becomes necessary to deal with the special conditions that arise. Before the use of electricity it was not necessary to have large generating systems to provide electricity. Since, within our experience, we do not ordinarily come into contact with objects that move close to the velocity of light, it is unnecessary to take into account the increase of mass that accompanies the increase of velocity.

Experiments

This unit consists of two demonstration experiments and two computations based on the principles discussed in the chapter. The current meter to be used in the first experiment must be quite sensitive; thus, it will require at least 50 turns of wire in the coil. Here again is an opportunity for stressing the problems of measurement. The explanation of the computations and the notations involved in the last two experiments will be set forth in the key to conclusions.

Key to Conclusions 1. The principle demonstrated is called thermoelectricity, which is the production of electricity by the action of heat on matter. The instrument constructed on this principle is the thermocouple ("couple" refers to the joining of two metals of different heat reaction), which is used for measuring temperatures in such out-of-the-way places as the bottoms of lakes.

2. The energy transformations of this experiment move from solar energy (light energy) through chemical energy (photosynthesis, which at this time should be discussed only as the process by which plants transform solar energy into chemical energy for growth), and finally into mechanical energy, which lifts the glass jar as the plant grows.

3. The computations for this experiment are as follows:

$$KE = \frac{mv^2}{2}$$

$$KE = \frac{1.7 \times 10^{-30} \times (3 \times 10^{7})^{2}}{2}$$

$$KE = \frac{(1.7 \times 10^{-30}) \times (9 \times 10^{14})}{2}$$

$$KE = \frac{15.3 \times 10^{-16}}{2}$$

$$KE = 7.65 \times 10^{-16}$$

$$KE = .000000000000000765 \text{ joules}$$

The fact that this computation can be done by the algebraic use of the exponents can be demonstrated for the students. The actual experiment done with a cyclotron must be carried out in a vacuum because the particle would otherwise expend all of its KE in collision with (doing work on) air particles.

4. The object will weigh 6.9×10^{-25} kilograms at 50 percent of the velocity of light and 30.18 kilograms at 98 percent of the velocity of light. It might be interesting for the students to compute the increase in their own mass, using the mass-velocity table.

Student's Supplementary Reading

Play with Plants. Selsam, Millicent E. William Morrow & Co., Inc., New York, 2.75

Riches from the Earth. Fenton, Carroll L. John Day Co., New York, 3.25

Energy and Power. DeCamp, Sprague. Golden Press Inc., New York, 1.49

Michael Faraday and the Electric Dynamo. May, Charles P. Franklin Watts, Inc., New York, 1.95

Films

Light and How It Travels. 45 frames. Jam Handy. Silent. Color. Rental: 4.75
Summary: Light is a form of energy. Some of its properties are shown.

Powering America's Progress. 16 mm. 25 min. Institute of Visual Communications Sound. Color. Free.
Summary: Coal—from mining to its use.

Laws of Conservation of Energy and Matter. 16 mm. 8 min. University of Illinois. Sound, Color, Rental: 2.65
Summary: Background for understanding these laws and their importance as basic principles of science.

Mystery of Time. 16 mm. 40 min. Moody Institute of Science. Sound. Color. Rental: 10.00
Summary: Shows time and space are relative standards of reference. Uses examples.

Behavior of Plants. 30 frames. Curriculum Materials Corporation. Silent. Color. Rental: 1.00
Summary: Plant responses to sunlight, moisture, and pull of gravity.

Particles of Matter. 16 mm. 14 min. University of Illinois. Sound. Color. Rental: 4.70
Summary: States basic theories and facts related to mass and energy.

Teaching Aids

Size and Nature of the Universe. The Theory of Relativity. Teller, Edward. 33 1/3 record. Spoken Arts 735. 4.00

Class Report—Coal. Booklet. 22 pp. National Coal Association, Education Division, Coal Building, 1130 17th St., N.W., Washington 6, D. C. Coal's form, history, production, and uses. Classroom quantities available free. Other publications available.

Oil Panels. Oil for the World. Charts and booklet, 140 pp. Standard Oil Co., Room 1626, Rockefeller Plaza, New York 20, New York. Single copy free to teachers. Nine posters on discovery and development of petroleum; illustrated booklet on history and story of oil.

What Is Relativity? Landau, Lev D. Basic Books, Inc., New York, 1.95

Space, Time and Gravitation. Eddington, Arthur. Harper & Brothers, New York, 1.35

Michelson and the Speed of Light. Jaffe, Bernard. Doubleday & Co., Inc., New York, .65

And There Was Light—The Discovery of the Universe. Thiel, Rudolf. Alfred A. Knopf, Inc., New York, .75

Chapter 1 2 3 4 5 6 7 **8**

STUDY TARGETS

In this chapter we conclude our consideration of the fundamental relationship between energy and mass that was first described by Einstein, and we give a foretaste of the material in the next book, SIMPLE MACHINES. The main points are these:

Einstein showed that energy and mass are so closely related that scientists now use the term "MASS-ENERGY" instead of talking about the two separately.

Matter and energy are different only in form. When an object is traveling near the speed of light, or when a nuclear reaction takes place, energy can be turned into matter and matter into energy. Such a change is called the MASS-ENERGY change.

Mass-energy changes are far too small to measure in either everyday occurrences or even in chemical reactions.

A machine turns all kinds of energy—electrical, muscular, kinetic, heat, and others—into MECHANICAL ENERGY.

1 Every second of every day the sun loses about 4,500,000,000 tons of its mass. Does this mean that mass is not conserved (that the law of conservation of mass is not true)? Why? What happens to this lost mass? In what form does part of it reach the earth?

ANSWER: No. This mass is converted to energy and is radiated. The lost mass becomes heat and light (and other types of energy) and reaches the earth in these forms.

REVIEW: Frame 389

2 Can you state in your own words what Einstein said about MASS and ENERGY that had not been said before?

ANSWER: He said that mass could be converted into energy: $E = mc^2$

REVIEW: Frames 380, 381, 385

3 What nuclear reactors are you likely to see every day (or every night)?

ANSWER: The sun and other stars
(but not the planets or the moon)

REVIEW: Frames 389, 390

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4 Calculate the work you must do on a 100-pound suitcase in the following situations:

A. In raising it a total distance of 19 feet straight up
B. In lifting it from the ground to a train platform 2 feet high
C. In trying to pull it but not succeeding in moving it at all

ANSWER: A. 1,900 foot-pounds
B. 200 foot-pounds
C. 0 foot-pounds

REVIEW: Frames 65–69, 408

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5 While a stone is falling, it has two kinds of energy. What are these two kinds of energy called? As the stone gets closer and closer to the earth, which kind of energy decreases and which kind of energy increases? Why? Which kind of energy is greatest at the instant the stone hits the ground?

ANSWER: The two kinds of energy are called potential energy (of position) and kinetic energy (of motion). Potential energy of position decreases as it is transformed into kinetic energy of motion. The kinetic energy of motion is greatest at the instant the stone hits the ground.

REVIEW: Frames 184–190

DISCUSSION STARTER The materials of Chapter 8 are chiefly a review and summation of Book 3. It is suggested that discussion starters previously unused or topics that have aroused the greatest interest be pursued as class experience indicates.

Experiments

This unit consists of four demonstration experiments and one simple calculation, for which all of the materials are provided in the Experiments section of the student's book. Experiments 1 and 4 require about one week for the results, although both are quite simple. The radioactive sample required for Experiment 4 can be obtained from most chemical and laboratory supply houses.

Key to Conclusions 1. The conclusions are demonstrated. This same principle is the cause of those movements of air we call wind. The movement of the water in the cylinder and in the tube is analogous to the movements of air that occur when heated air rises and cooler air rushes in to take its place.

2. This process is called electrolysis. The electrical energy does work in separating the sulfur and the copper. The process of forming a coating, such as the copper does on the carbon rod, is called electroplating. One use of this process is in retrieving metal that is dissolved in sea water.

3. Photography works on the same principle.

4. The word means, literally, "drawing done by rays." In laboratories that handle radioactive materials the workers wear special locketlike pins containing film tags. These film tags are developed at the end of each day or week to show the amount of radiation the wearer has come in close contact with.

Student's Supplementary Reading

Engines. DeCamp, Sprague. Golden Press, Inc., New York, 1.49

Solar Energy. Branley, Franklyn M. Thomas Y. Crowell, Inc., New York, 3.00

Albert Einstein. Beckhard, Arthur. G. P. Putnam's Sons, New York, 2.50

Energy. Lodge, Oliver. John F. Rider Publisher, Inc., New York, 1.25

The Universe and Dr. Einstein. Barnett, Lincoln. Paperback. Mentor Books. .50

Films

Lever Age. 16 mm. 21 min. Shell Oil Co. Sound. Color. Free
Summary: History of mechanical progress

Mechanical Advantage. 48 frames. Your Lesson Plan. Sound (record) and captions, Color. Rental: 3.00
Summary: Basic principles

Introduction to Engines. 49 frames. Your Lesson Plan. Sound (record) and captions, Color. Rental: 3.00
Summary: Concepts and principles—scientific attitudes behind the facts

Energy from the Sun. 16 mm. 23 min. Encyclopaedia Britannica. Sound. Color. Rental: 2.50

Summary: How solar energy is transmitted and why; how some of the mass is converted into energy.

Experiment: Solar Energy. 16 mm. 23 min. National Association of Manufacturers, Sound. B&W. Rental: 1.50
Summary: Suggests that soon the power of the sun will be directed into new and exciting services to mankind: solar heating and cooling of homes, etc.

Teaching Aids

Bell Solar Battery. Film. Request through local Bell Telephone business office. Color. Sound. 12 min. Invention of the battery, how it is made and how it works.

What Is a Machine? Syrocki, B. J. Benefic Press, Chicago, Ill., 1.80

How to Do an Experiment. Harcourt, Brace and World, Inc., New York, 2.60

Our Land of Machines. 32 pp. Charles E. Merrill Books, Inc., Columbus 16, Ohio, .28. How machines serve modern America.

You and Machines. Booklet. 15 pp. Channing L. Bete Co., Inc., Greenfield, Mass., .25. Development of machines and how they raise the standard of living.

Film Suppliers

Films listed as available from the University of Illinois and Indiana University may also be rented from local rental libraries in your area.

AV-ED Films
7934 Santa Monica Bouelvard
Hollywood 46, Calif.

Churchill-Wexler Film Productions
801 N. Seward Street
Los Angeles 38, Calif.

Curriculum Materials Corporation
1319 Vine Street
Philadelphia 7, Pa.

Encyclopaedia Britannica Films
1150 Wilmette Avenue
Wilmette, Ill.

Film Associates of California
11014 Santa Monica Boulevard
Los Angeles 25, Calif.

Filmstrip House
347 Madison Avenue
New York 17, N. Y.

General Motors Corporation
Public Relations Staff
Film Library
General Motors Building
Detroit 2, Mich.

Institute of Visual Communications, Inc.
Modern Talking Picture Service
40 E. 49th Street
New York 17, N. Y.

Jam Handy Organization
Film Distribution Department
2821 E. Grand Boulevard
Detroit 11, Mich.

Moody Institute of Science
11428 Santa Monica Boulevard
Los Angeles 25, Calif.

National Association of Manufacturers, Film Bureau
2 E. 84th Street
New York 17, N. Y.

National Bureau of Standards
Office of Technical Information
Washington 25, D.C.

NET
Indiana University
Audio-Visual Center
Bloomington, Ind.

Prentice-Hall Inc.
Educational Book Department
Englewood Cliffs, N. J.

Science Slides Company
22 Oak Drive
New Hyde Park, Long Island, N. Y.

Shell Oil Company
Film Library
624 S. Michigan Avenue
Chicago 5, Ill.

UNESCO
801 Third Avenue
New York 22, N. Y.

University of Illinois
Visual Aids Service
Division of University Extension
Champaign, Ill.

Your Lesson Plan Filmstrips
1319 Vine Street
Philadelphia 7, Pa.

S.C.E.R.T., West Bengal
Library
Calcutta
25/3, B. C. Road

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TEA

THESE TWENTY BOOKS PROVIDE FOR YOUR STUDENTS' STUDY OF GENERAL SCIENCE

Matter in Motion

1 Motion
2 Force
3 Energy and Work
4 Simple Machines

Flow of Energy

5 Sound
6 Heat
7 Light
8 Electricity and Magnetism

Structure of the Universe

9 Atoms
10 Molecules
11 Earth
12 Universe

Patterns of Life

13 Units of Life
14 Chain of Life
15 Human Body
16 Adaptation

Science at Work

17 Climate, Weather, and Man
18 Resources and Industry
19 Communication
20 Frontiers of Science

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